Eco-efficiency of waste management
A case study of the Norwegian deposit and recycling system for PET bottles

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Abstract

The Norwegian system for depositing and recycling of PET bottles (Resirk/PET system) started in May 2000, and is based on Norsk Resirk's mission of improving cost- and environmental efficiency of this system. Has this been achieved? What can explain the changes that occurred in the system during recent years?

I have found that the eco-efficiency of the Resirk/PET system increased considerably every year between 2000 and 2003. The net greenhouse gas (GHG) emission was improved from -562 kg CO_2e (562 kg CO_2 equivalents avoided generated) for waste management of one tonne consumed bottles in 2000 to -1442 kg CO_2e per tonne in 2003, while the net cost was reduced from 4062 €/tonne in 2000 to 2683 €/tonne in 2003. This eco-efficiency improvement was very much driven by the increased volume and return rate of PET bottles during this period. The environmental performance of the Resirk/PET system was high compared to other waste management systems for PET bottles, while the economical performance was considerably lower.

The interactive development of the bottled non-carbonated mineral water Imsdal contributed significantly to the increase of the Resirk/PET system's volume and return rate and hence the system's improved eco-efficiency. A white spirit sabotage on Imsdal in August 2002 contributed to the development of Imsdal as well as the Resirk/PET system's change of the design and material specification for participating PET bottles.

By combining the quantitative eco-efficiency framework with the qualitative framework of interactive resourced development, information about how much eco-efficiency of a defined system has changed, as well as an understanding of reasons for changes within the system, has been acquired. Such a combination should be possible to apply for analysis of other systems as well, and may be a valuable contribution to the field of industrial ecology since the methods complement each other in a fruitful way.

The eco-efficiency of the Resirk/PET system can be improved further by:

- Regarding used PET bottles as a resource to be applied for production
- Reducing packaging tax for PET bottles
- Increasing the bottle deposit
- Keeping the PET specification updated
- Improving collection efficiency
- Improving cost efficiency of marketing and information
- Increasing compaction and filling degree of reverse vending machines
- Considering automatic sorting
- Keeping focus on producing high quality PET flakes.

In addition to having showed that the approaches of eco-efficiency and interactive resource development can be combined, this thesis may have implications on how eco-efficiency can be quantified in waste management systems, and how the concepts of adaptation and friction in resource structures are dealt with.

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Contents

List of figures

List of tables

1. Introduction

The Norwegian deposit- and recycling system for one-way PET bottles, Resirk, has been in operation since May 2000. In 2003, 75 % of the bottles in the system were returned and recycled into clothes and other products. But what does this system really look like, and how does it change? Is it environmental friendly? Is it costly? This thesis is about the eco-efficiency of PET bottles in the Resirk system and how these bottles and other resource elements in the system have interactively developed during recent years.

1.1. About waste and PET recycling

Recycling of waste into new products is believed to be an important contribution towards sustainable development, see for example Graedel and Allenby (1995). When recycling, or reusing, one avoids end-of-life products such as disposed radios and furniture, and used packaging, polluting and taking up space in streets or landfills. Another important reason is the fact that recycled end-of-life products can replace alternative use of virgin material and hence the costs and emissions from producing these. However, before being more technical, let us have a brief look at waste in a historical context.

According to Waste Watch (2004), a British organization whose aim is to promote and support waste reduction, reuse and recycling, the history of waste can be traced back over thousands of years. Until the Industrial Revolution, when materials became more available than labour; reuse and recycling was common. Nearly 4000 years ago there was a recovery and reuse system of bronze scrap in operation in Europe and there is evidence that composting has been carried out in China for a very long time. Reuse and recycling has always existed in the form of salvage, an age-old tradition stretching forward to the Rag-and-Bone men. Traditionally, recovered materials have included leather, feathers and down, and textiles. Recycling included feeding vegetable waste to livestock and using green waste as fertiliser. Pigs were often used as an efficient method of disposing of municipal waste. Timber was often salvaged and reused in construction and ship-building. Materials such as gold have always been melted down and re-cast numerous times. Later recovery activities included scrap metal, paper and non-ferrous metals. However, as city populations increased, space for disposal decreased, and societies had to begin developing waste disposal systems. Today, such services are offered, though to a varying degree, in large parts of the world.

There have been significant changes in the composition of household waste over the last 100 years which can be traced back to fundamental social and economic shifts affecting the way we live our everyday lives, as is traced in the above chronology (Waste Watch 2004). Waste can be difficult to quantify, and it is only over the last few decades that there have been any real attempts at estimating the composition of household waste. Some of these are given in the diagram below.

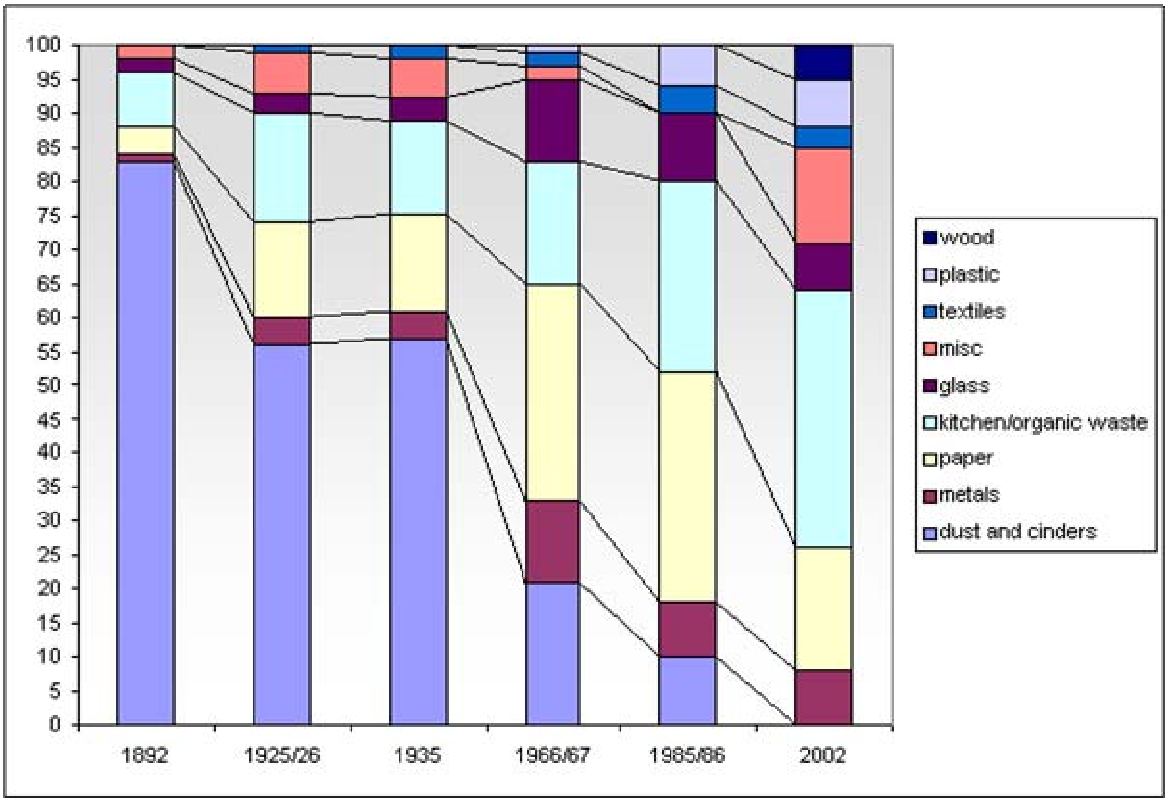

Figure 1.1: Composition of household waste in the United Kingdom 1892 – 2002 (Waste Watch 2004)

The diagram, which gives an overview of the household waste composition in the UK, shows that kitchen/organic waste and paper have been the largest fraction for the last 40 years. However, plastic, mainly in terms of Polyethylene Terephthalate (PET) bottles and other types of packaging, are also to an increasing degree making an impact.

PET, which is a strong but lightweight form of clear polyester, was first developed for use in synthetic fibers in 1941. In the mid 1960s PET began to be used for packaging films, and in the 1970s the technique for blowing bottles was commercially developed. Today, bottles used for beverages, represent by far the most significant user area for PET. The first PET bottles was recycled and turned into a bottle basecup in 1977 (Petcore 2005).

In 2003 around 10 million tones of bottles, or around 350 billion PET bottles[1], were consumed worldwide (PCI January 2004). The annual global increase in consumption of PET bottles between 1990 and 2003 was around 10 % and this growth is expected to continue in the coming years as well. In addition to being lightweight, another environmental advantage of using PET for beverage purposes, is that in principle they are 100 % recyclable. However, less than 20 % of the world's consumed PET bottles are

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[1] Based on the average weight of a PET bottle in Norway, which is found to be around 35 gram

collected, transported, sorted, reclaimed and recycled into products such as clothes, carpets, fruit boxes, automotive parts, and new PET bottles. A large part ends up at landfills, or to incineration with or without energy recovery. There are several reasons for this:

- Many countries and cities do not offer collection and sorting of used PET bottles due to costs and/or lack of development reasons.
- Consumers are to a certain degree not concerned about and not aware of the service of PET collection
- Due to bad sorting and hence presence of glass fragments, dirt, metal, and other plastic types, PET bottles collected for recycling are sometimes rather incinerated or deposited at landfills.
- Some PET bottles contain substances such as PVC, glue, colour, barrier layers or other additives and are hence non- or less-recyclable
- The demand of used PET for recycling into new products is at periods, saturated.

1.2. *Is it worth recycling?*

According to SITA (2004), the waste hierarchy was first introduced into European waste policy in the European Union's Waste Framework Directive of 1975. In 1989 it was formalized into a hierarchy of management options in the European Commission's Community Strategy for Waste Management, and further endorsed in the Commission's review of this strategy in 1996. The EU's waste management policy is still based on the waste hierarchy. According to the waste hierarchy, which is used by many decision makers as guidance for waste management strategies, the prioritized order should be:

1. Waste reduction
2. Reuse
3. Recycling and composting
4. Incineration with energy recovery
5. Incineration
6. Landfill with energy production
7. Landfill

Even though it is supposed to be a rule of thumb for waste in general, many representatives from government, industry, NGOs (nonGovernmental organizations) and academia tend to think this is an absolute rule which is also valid for PET bottles. Others argue that the waste hierarchy is not able to grasp the economical advantages, and disadvantages, of the various management options for used PET bottles. On the discussion of the extent to which waste reduction of PET bottles should be strived, there seems to be an agreement than one should continue to try to reduce the weight of the bottles and hence reduce the PET waste generated (Petcore 2005). However, there are more disagreements on the issue of reduction of consumption of PET bottles also is to be preferred. NGOs tend to think that this should be the optimum goal, academics are more split, whereas industrial representatives often see this as a threat to their business. In Norway, a committee within the Norwegian Business Confederation has initiated the concept of packaging optimization as an alternative to packaging reduction. The main argument is that it is better, also from an environmental point of view, to use an optimized amount of packaging to preserve the main product than to minimize the amount of packaging applied and hence risk breaking the main product (NOU 2001). As for the issue of the importance of re-use, Lerche Raadal et al (2003) have done a study in Norway where they have found that from an environmental point of view one-way PET bottles are performing equally well as refillable PET bottles. RDC-Environment & Pira International (2003) have found that the costs and benefits of refillable and non-refillable (one-way) PET bottles are in the same order of magnitude. The internal cost of refillable is considerably higher than of non-refillable and compensates the refillable's lower environmental impact. The big issue among scientists and consultants is, however, whether PET bottles should be recycled, incinerated, or disposed at landfills.

Several studies have concluded that recycling of PET bottles is not necessarily a better solution than energy recovery, incineration and landfilling, see for instance Bruvoll (1998), GUA (2000) and Eggels (2000). However, others have concluded differently (Lerche Raadal et al 1999, Wollny and Schmied 2000, Lerche Raadal et al 2001, Wollny et al 2001). Not surprisingly, the conclusions of these studies differ in accordance with the methods that are applied to evaluate the preferable waste management option:

- The life cycle assessment (LCA) studies find that recycling is environmentally preferable to incineration and even more to landfill, see for example Lerche Raadal et al (1999, 2003)
- Use of life cycle costing (LCC) has identified that the economical cost of recycling is higher than for incineration and in particular for landfill, see for example RDC-Environment & Pira International (2003)
- The conclusions from costs benefit analysis (CBA) studies, which include both internal (financial) cost and external (environmental and social) cost evaluations, differ, see for example Lerche Raadal et al (2001) and Bruvoll (1998)

For more information about LCA and LCC, see Section 3.3. Wrisberg et al (2000) present CBA and other analytical methods "for environmental design and management in a systems perspective"

As it in any case not will be possible to reuse or recycle all used PET bottles, a combination of various waste management solutions are often recommended (APME 2000, RDC-Environment & Pira International 2003). RDC-Environment & Pira International were hired by the European Union to "evaluate costs and benefits of the achievement of reuse and recycling targets for the different packaging materials in the frame of the packaging and packaging waste directive 94/62/EC", see below for more information about the packaging and packaging waste directive. This study concludes, from a cost-benefit point of view, that the average optimum recycling rate for PET bottles in EU15 countries is 28 - 38 %. The remaining PET bottles should go to incineration or landfill.

1.3. Laws, regulations, systems

The European Union may be the most ambitious region in terms of focus on environmental- and cost efficient waste management of PET bottles and other packaging. In 1994, the European Union Directive on Packaging and Packaging waste was adopted as 94/62/EC. In December 2001, the European Commission put forward a proposal revising this directive. After many discussions between the European Council and the European Parliament, the proposal was agreed in December 2003 and amended under the code 2004/12/EC in February 2004 (European Union 2004). The directive will be implemented into national legislation by autumn 2005.

The packaging and packaging waste directive says that the material recovery (material recycling and energy recovery) targets should be increased to minimum 60 %. No maximum is specified. Incineration with energy recovery is included in this target. Material recycling has been increased from 25-45 % required by the 1994 directive, to 55 % minimum and 80 % maximum for the revised one. Moreover, the directive requires specific recycling percentage to be reached by each packaging material. For plastic packaging, including PET bottles, 22.5 % recycling is required. These targets need to be met by end 2008 for all Member Countries, apart from Greece, Ireland and Portugal who can wait until 2011, Cyprus, the Czech Republic, Estonia, Hungary, Lithuania, Slovakia and Slovenia who have to commit by 2012, Malta (2013), Poland (2014) and Latvia who has until 2015 to reach the recycling goals. Norway is a member of the European Economic Area (EEA) and is hence obliged to meet the requirements by 2008.

EU directive 2004/12/EC states that it is the producers of beverages and other packed goods, that are responsible for the recovery of the packaging they use, see Lindhqvist (2000) for more about the principle of extended producer responsibility. However, most producers and users have decided to transfer this responsibility to an approved national organization, and hence these producer responsible organizers (PROs) become juridical and/or economically responsible for establishing recovery systems for PET bottles and other packaging. Hence the mandate of producer responsible organizers (PROs) is to ensure that a recycling and waste management system is organized and operated in a sound environmental- and economical manner. Petcore (2005) gives an overview of all PROs for plastics in Europe. The PRO, which normally is based on a national level, is usually financed through an administration fee producer and importers have to pay for each packaging unit they introduce in the market.

The PROs are normally involved in the material from when it occurs as used packaging until it is disposed at landfills, incinerated with or without energy recovery, recycled, or reused. Sometimes they own the materials to be treated, sometimes not. The PROs are normally not owners of the facilities needed to treat used packaging. Instead they support municipalities, retailers, sorters, transporters and reclaimers to do the job of collection, sorting, transporting and reclaiming of packaging into secondary raw material ready for recycling into new products. In many cases, the PRO is a non-profit company or organization owned by the producers, importers and trades. Hence, if the costs for waste management of the used packaging are reduced, the administration fees producers and importers pay are reduced accordingly.

In order to reach the recycling goals set by the EU packaging directive and the PROs, various systems for collection of used PET bottles are available. It is up to each single Member State, and in some cases each single municipality, to decide on what collection method is most suitable. Kerbside collection requires citizens to separate recyclable materials from their other household waste, by placing them in specific waste bags. 40-60 % of the recycled material from Europe is collected in this way (Petcore 2005). Another alternative is drop off locations, or bringing igloo solutions, which requires citizens to collect and separate their used PET bottles and then bring them to specific locations. Around 10-15 % of the PET bottles are recycled through this collection method. The return vending system requires bottles to be returned to a place where return vending machines (RVMs) are located, often at retailers. Consumers place the used PET bottles in the RVM and receive a coupon or a token in return. According to Petcore (2005) 15-20 % of all recycled bottles from the EU market are collected in this way. Finally, we have the refill and deposit system, often including RVMs, which entails bottles to be sold with refundable deposits. This approach is most common in Scandinavia, and some other countries (Petcore 2005)

In Norway the national systems for collection and recycling of beverage packaging are organized in various ways. There are igloos where the consumers can return glass bottles on which there are no deposits. The beverage cartons are collected at kerbsides through the municipal household waste system. Refillable deposit bottles of glass and PET are returned by consumers in shops, and the breweries organize the system for return of these bottles for refilling at the various breweries and bottling plants. The Resirk system is the system for recyclable one-way aluminium cans and PET bottles. In the same way as for refillable bottles, the consumers return the empty bottles in shops, kiosks, petrol stations, and supermarkets and get the paid deposit refunded.

The Norwegian deposit and recycling system for one-way beverage cans and PET bottles, the Resirk system, was launched in 1998. As I am only concerned about the PET part of the Resirk system, I will from now on refer to this system as the “Resirk/PET system”. The first PET bottles in Resirk/PET system were registered in May 2000, one year after the first cans were introduced. Norsk Resirk, the main decision maker and PRO in the Resirk system, has been given a mandate by the Norwegian Ministry of Environment, which they have translated into a mission to “establish and operate a non-profit deposit- and recycling system for one-way beverage- and soft drink containers which (Norsk Resirk 2002):

- Has a high objective in recycling, 90-95% long term.
- Is environmental, competition-neutral and cost-efficient.

Are these goals about to be achieved? Are they realistic?

In 2003 Lerche Raadal et al (2003) conducted a life cycle assessment (LCA) study of the Resirk/PET system to find out whether it was preferable to the current deposit system for *refillable* bottles. The background for this study was a political discussion on whether or not it would be a good idea to reduce the packaging fee on one-way bottles. This might create an incentive for beverage producers to change from refillable- to one-way PET bottles. If this is done, it is expected that the cost efficiency as well as the recycling rate of the Resirk/PET system will increase considerably. The study concludes that the environmental performance of the two systems is approximately the same. However, it is worth mentioning that this is valid only if a certain amount of secondary PET material is applied to produce the PET bottles, and at the same time more than 90 % of the one-way PET bottles in the Resirk/PET system are recycled. Is this realistic, and in that case what would be the cost? The best way to answer such questions would be to look into the Resirk/PET system in a detailed and comprehensive manner and see whether the cost- and environmental efficiency has improved since start up, and furthermore to try to understand how and why changes of these efficiencies occur.

1.4. Purpose and research questions

The purpose of this thesis is to evaluate to what extent the Resirk/PET system has moved towards Norsk Resirk's mission of being cost- and environmental efficient, and furthermore to explain what parameters are critically influencing this efficiency. Another aim is to examine the development of the PET bottles in the Resirk/PET system and look at how this development has contributed to the cost- and environmental efficiency of the system. A final important aim is to see whether the interactive resource development approach can contribute to the field of industrial ecology.

I will answer the following research questions:

1. How has the eco-efficiency in Resirk/PET system changed during recent years?
2. What are the influencing parameters to the eco-efficiency?
3. What factors shape and explain these parameters?
4. How can eco-efficiency and interactive resource development be combined to make a contribution to the field of industrial ecology?

To answer research question 1, I will use the framework of eco-efficiency, which I will modify to be applicable for evaluation of waste management systems by using selected indicators. When doing such a life cycle based eco-efficiency analysis in a systematic way, I also believe I will be able to find what parameters are influencing the quantified eco-efficiency.

Whereas the first two research questions will be answered by the quantitative approach of eco-efficiency, research question 3 will be dealt with by using the interactive resource development approach, one of several aspects of the concept of industrial network theory.

The answers to research questions 1-3 aim to give empirical contributions to the field of industrial ecology. The theoretical and methodological industrial ecology contributions of my thesis aim to be given by combining the quantitative framework of eco-efficiency ("how much") with the qualitative framework of interactive resource development ("why"). I hope to be able to do this by answering research question 4.

1.5. Structure of thesis

In this chapter I have put the Resirk/PET system in a practical context, and motivated and presented the research questions.

Chapter 2 deals with the empirical basis of this thesis, and gives a description of the background and function of the Resirk system for deposit- and recycling of PET bottles.

In Chapter 3 I will present the theoretical- and analytical framework of this thesis. The industrial ecology perspectives of life cycle system approach, eco-efficiency and interactive resource development within the industrial network theory.

My methodological approach to this thesis as well as definitions, limitations and assumptions in the research methods applied, are given in Chapter 4.

Chapter 5 presents results and analysis. First I quantify the eco-efficiency and find important factors to eco-efficiency, before I show how the Imsdal bottle is developed and how this development is connected to the eco-efficiency

Discussions of uncertainty in the eco-efficiency results and the interactive resource development analysis are given in Chapter 6.

Chapter 7 sums up the practical implications and theoretical contributions of the thesis, and gives my suggestion for further work.

2. The Resirk/PET system

In this chapter we will have a look on the establishment of the Resirk/PET system, how it functions, and what role the different parts, both upstream and downstream of bottle consumption, play.

2.1. Establishment of the Resirk system

The national systems for collection of beverage packaging are organised in various ways in Norway. There are igloos where consumers can return no-deposit glass bottles. Citizens place beverage cardboards in kerbside bins, which are organized through the municipal household waste collection system. Refillable PET- and glass bottles are returned by consumers at stores, petrol stations and kiosks where the paid bottle deposit is refunded. The breweries organize further transport, sorting, washing and refill of new beverage into these bottles. The Resirk system is the system for recyclable single use aluminium cans and PET bottles. Similarly as for refillable bottles, the consumers return the empty bottles at retailers, and get the paid deposit refunded there.

The Norwegian deposit system for one-way beverage cans and PET bottles, the Resirk system, was launched in 1998. However, there has been a deposit system for refillable bottles for more than 40 years operated by the breweries. Until the launch of the Resirk system, beverages in one-way bottles and cans have, for environmental and domestic industry employment reasons, been held back by high packaging taxes.

Inspired by the deposit system for single use bottles in Sweden, established by Swedish Returpack in 1984, there were ideas on establishing a deposit system for one way beverage containers in Norway by the late 1980s. The period between 1989 and 1996 was a time for political discussions, studies, analyses, and coordinated strategic work between Norwegian retailers and breweries, before Norsk Resirk Ltd was eventually approved by the Norwegian Pollution Control Authority and Ministry of the Environment. Norsk Resirk was founded on the 11th of November 1996. (Norsk Resirk 2002). Their mandate from the Norwegian Ministry of Environment was to "establish and operate a deposit- and recycling system for one-way beverage- and soft drink containers". This included and still includes cans made of aluminium and steel and bottles made of PET. The agreement between the government and industry also stated that there still should be a tax on such packaging, but that this tax from now on should be related to obtained national return rate for cans and bottles, respectively. Since establishment, Norsk Resirk has been non-profit based and owned by retailers (50 %) and breweries (50 %). Their mission of "90-95 % recycling in long term", carried out in an "environmental, competition-neutral and cost efficient way" has been guide since the system was established.

Before Norsk Resirk decided to go for a deposit model, a non-deposit solution based on either kerbside or igloos was considered. However, even though the advantages of lower investment cost for these solutions, the deposit system was chosen. The strongest arguments for this choice were as follows (Norsk Resirk 2002):

- Deposit gives consumer incentives for returning the bottles
- Return points in shops ensure good consumer availability
- Norwegians already had good deposit-return habits due to the well established system for refillable bottles
- Material fractions to be recycled from deposit systems are generally far higher than the quality collected through curbside or igloo system.

The system for deposit and recycling of aluminium and steel cans was up and running from May 1999, whereas the first PET bottles were registered in the system a year later, in May 2000. In the rest of this thesis I will focus on the PET part of the Resirk system, and I will, as mentioned in Chapter 1, refer to this as the Resirk/PET system.

2.2. How does the Resirk/PET system function?

The increasing use of one-way recyclable PET bottles in recent years in Norway is mainly a result of the Norwegian Ministry of Environment's decision to reduce environmental tax on one-way beverage packages to a level dependent on the national recycling rates for the current packaging type. In August 2003 more than 130 different types of PET bottles were registered to be part of the system. In 2003 around 1700 tonnes of PET bottles were consumed, while 1275 tonnes, or around 75 %, were returned for recycling purpose. As we can see from Figure 2.1, which shows the material and money flow of the system, several actors are a part of the Resirk/PET system. The green arrows show the life cycle of the PET bottles, including the production of bottles, filling of bottles at breweries, distribution to retailers where bottles are sold and returned after consumed, pick up of empty bottles from shops, baling at depot, and eventually recycling. Norsk Resirk covers the costs for organization and operation of major parts of this loop. These costs include handling a fee to retailers for receiving and taking care of the bottles, a fee to the pick up agent for the transport, as well as a fee to cover costs for sorting and baling at the depots. In 2002 the handling fee was 0.25 NOK[2] per bottle to retailers with reverse vending machine (RVM) and 0.10 NOK per bottle for retailers with manual sorting. Retailers that have invested in RVMs get higher support because such a machine reduces the overall cost of the Resirk/PET system due to automatic recognition and compaction of bottles.

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[2] 1 NOK = 0.125 € (approximate average exchange rate 2000-2003)

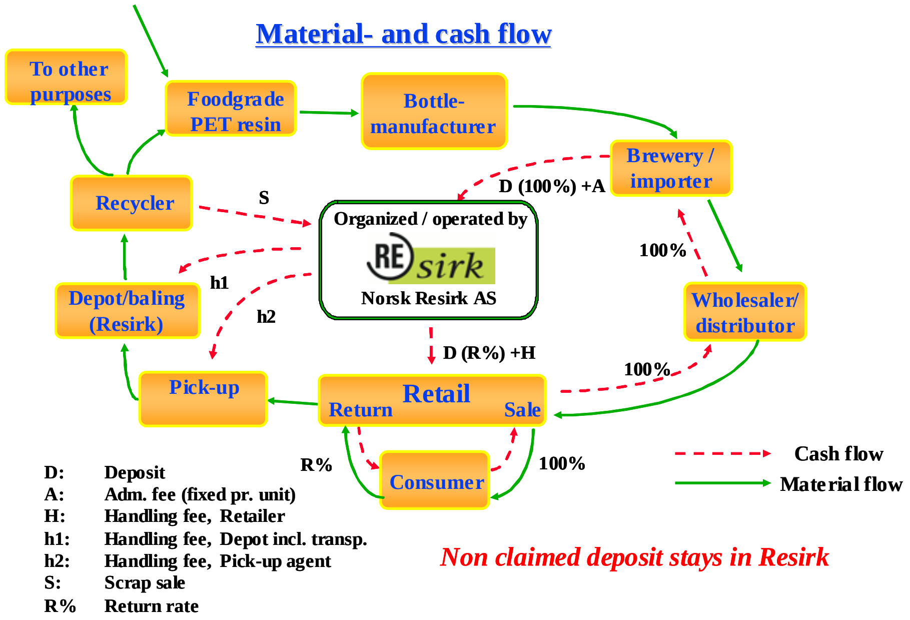


Figure 2.1: Material- and money flow in the Resirk/PET system (Norsk Resirk 2002)

In order to cover the above mentioned fees and other administration and running costs, Norsk Resirk receives income from an administration fee from producers and importers who pay to participate with their bottles in the Resirk system, from non claimed deposit for not returned bottles (as well as an insignificant income from the sale of the baled PET bottles to foreign reclaimers), see Figure 2.2 below. Actually the non- claimed deposit is an important source of income for Norsk Resirk, and it is higher the lower the return rate is. However, their aim is to run a non-profit organisation, and in order to do that they have to make sure that the costs equal the income. That means that increased income from non-claimed deposits at lower return rates can be spent to reduce the administration fee, Norsk Resirk's other main income.

Another way of spending this "unwanted" income is for example to increase the marketing and information efforts towards consumers to convince them to return the bottles and cans. As Figure 2.2 indicates the packaging tax is reduced when the recycling goes up, and there is hence no incentive for Norsk Resirk to keep the return rate low. The reason for lack of such an incentive is the fact that the producers of beverages own a large part of Norsk Resirk. They are, as payers of packaging tax, first and foremost concerned about obtaining as high national return rate as possible to make the tax on the beverage bottles as low as possible.

As one is concerned about the costs of bringing post consumer PET bottles into new life, it should be notified that Norsk Resirk's income from administration fees and non-claimed deposits are not included when calculating the net cost of the system, see chapter 5.

Producers and importers who to sell beverages in one-way PET bottles in Norway are free to choose whether they want to have their products in the Resirk/PET system or whether the bottles should be a part of the ordinary waste management systems offered by the municipalities. However, even though they have to pay an administration fee for each bottle introduced in the system, the reduction of the packaging tax they have to pay for one way beverage packaging, clearly outweighs these extra costs of 0.20-0.40 NOK bottle. In addition the producers and importers have to pay 30,000 NOK to become a member of the system as well as 5,000 NOK per bar code (bottle type) registered.

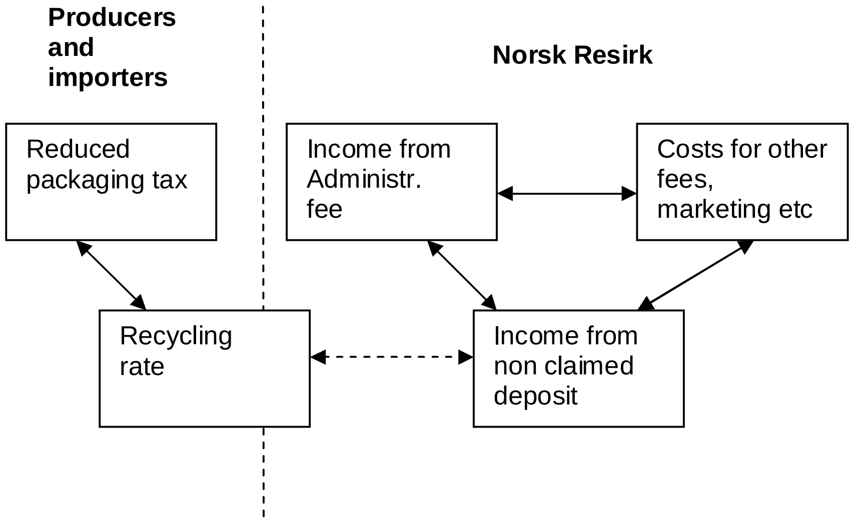


Figure 2.2: Relation between packaging tax and recycling rate, and between Norsk Resirk's incomes and costs

As mentioned above, the packaging tax on each and every PET is, through regulations related to return systems for beverage packaging, dependent on the national recycling rate of all PET bottles during a year (Norwegian Ministry of Environment 1993). Table 2.1 below shows the relation between the packaging tax per PET bottle at varying return rates. The tax reduction as well as the basis for calculation of recycling rates only applies for PET bottles that are registered in the Resirk/PET system.

Recycling rate [%]	Packaging tax [NOK/PET bottle]
0	3.37
25	3.37
50	2.00
75	1.48
95	0.85
100	0.85

Table 2.1: Packaging tax per PET bottle as a function of national recycling rate, as of August 2003

The packaging tax for one-way beverage containers consists of two parts; a static ground tax (0.85 NOK per bottle in August 2003) and an environmental tax. If comparing the total packaging tax for a PET bottle that participates in the Resirk/PET system with a similar bottle that is not a part of the system, the tax in August 2003 for "Resirk bottles" was 1.48 NOK, whereas similar bottles not registered in the deposit had a tax of 3.37 NOK per bottle. This means that the difference for the beverage producer is almost 1.89 NOK per bottle and this is the reason why they prefer to pay Resirk 0.20-0.40 NOK per bottle

In order to be automatically recognised by the return vending machine (RVM) at the retailer, or, if only manual reception is offered at the retailer, in a similar way in so-called petimeters at the semi-depot, each bottle type needs a barcode. However, before a new bottle type can be registered with its barcode and included in the Resirk/PET system, one has to make sure that the bottles fulfill the design- and material specification for PET bottles (the "PET spec"). The PET spec valid for the 2000- 2003 period is given Appendix B, while the new PET spec that was approved by Board of Norsk Resirk is shown in Appendix C. The purpose of the PET spec is to make sure that the bottles' size and shape are in accordance with the requirements of the return vending machines and petimeters, and moreover, to prevent undesired materials being included in the recycling process of the bottles.

2.3. Resirk/PET's recycling loop

In Figure 2.1 in the previous section the recycling loop of the Resirk/PET system was briefly presented. In this section I will go into more detail and give a description of what is happening within each of the life cycle activities. I will start with the activities upstream of used PET bottles, before I explain what happen with the used bottles, i.e. the downstream activities.

2.3.1. Upstream activities

Production of primary PET resin
In order to make PET bottles, a raw material of high quality bottle grade PET resin is needed. Crude oil and natural gas are extracted to produce ethylene and paraxylene, the latter is further processed into its derivatives: ethylene glycol and terephthalic acid, which are eventually made to react to obtain the PET resin (Danish Ministry of Environment and Energy 1998).

Production of pre-forms and bottles
Production of PET bottles is defined to include the two steps of pre-form manufacturing and bottle manufacturing. High quality primary PET resin or, on rare occasions,

secondary PET resin, in the shape of small cylinders called pellets, is melted and injected into a mould to make a pre-form. The pre-form, a sort of test tube shorter than the bottle will be but with thicker walls, is then blow-moulded. During the blow-moulding phase, high-pressure air is blown into the pre-form allowing it to take the exact shape of the mould it is set into. The final product is a transparent, strong and lightweight bottle. (Petcore 2005)

Washing, filling, packing and registration

The blow-moulded PET bottles are washed and filled with beverages such as soft drinks, mineral water, or non-carbonated drinks at the beverage producers' bottling plants. Thereafter labels or sleeves and closures are placed on the bottle to have a final product ready for distribution.

A few of the beverage producers that participate in the Resirk/PET system buy pre-forms and blow-mould them into PET bottles before they immediately afterwards wash and fill the bottles with beverage. Both operations are carried out at the bottling plant. However, most of them buy prepared bottles ready to be filled. Bottles must be registered at Norsk Resirk before they can be introduced into the system. In order to be registered the bottles must fulfill the design- and material specification given in Appendix C.

Distribution

The distribution of the filled bottles to the retailers is mainly carried out by the beverage producer's own trucks. However, some of the bottles are distributed by the wholesaler's distribution network as well. Some of the beverages in the systems are imported. In those cases the importers have registered the bottles in the Resirk/PET system before being able to import them. To enter the system, the imported bottles must fulfill the same design and material requirements as bottles filled in Norway.

Sale and consumption

At retailers such as supermarkets, kiosks and petrol stations the filled PET bottles are sold. The price the consumer pay includes a deposit, which is 1.00 NOK for bottles up to 0.5 liters and 2.50 NOK for larger bottles.

2.3.2. Downstream activities

Return of the PET bottles

All sellers of beverages are obliged to accept returned bottles, and consumers in Norway to a large extent return their used PET bottles to these retailers when shopping. In 2003 close to 40 million - out of the approximately 50 million registered PET bottles - were returned. The consumers get the deposit refunded by the retailer and thereafter the retailers get the deposit refunded from Norsk Resirk. Non-claimed deposit for bottles not returned stays as mentioned before with Norsk Resirk.

Most of the shops have a return vending machine (RVM), whereas some of the smaller shops, kiosks and gas stations usually check and count the bottles manually. RVM suppliers are operating according to Resirk's requirement and third party audits and Resirk approval is required to enter the market. The recognition of the PET bottles in the RVMs is primary based on bar code recognition, and secondary on shape recognition. There is no metal or colour sensor in the machines. Around 85 % of the returned bottles go through the 2500 RVMs all over Norway, whereas 15 % are received at manual return points.

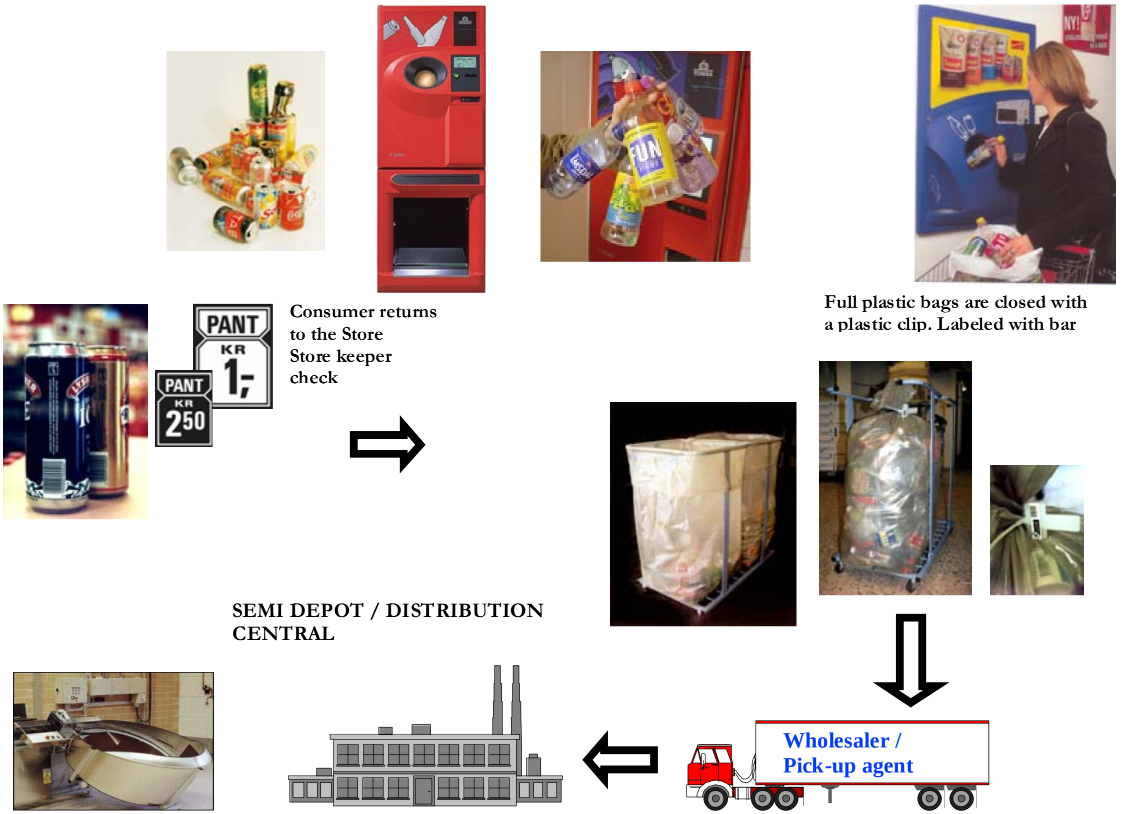
The manually received bottles are label checked and placed (non-compacted) in plastic bags before closed with a plastic clip and labelled with bar code when full. The bottles delivered to RVMs are bar code recognized and –registered before being compacted to reduce their volume by approx 50 % before being placed in transport bags. These plastic bags are also closed with a plastic clip ready to be transported. Non-registered bottles and bottles with unreadable bar market codes bottles are rejected. In order to avoid consumer cheating at the reverse vending machines, by for instance placing bar codes on toilet roles, the bottles are also shape recognized.

Information registered in the RVMs on the number and type of bottles that are returned, is transferred to the RVM suppliers and later on to Norsk Resirk.

Pick up and operations at semi-depots

The return transport of the plastic bags containing the PET bottles is carried out with the wholesaler's distribution cars in the same operation as they deliver groceries to the retailers. Retailers with no wholesaler connection have the empty bottles picked up by a third party pick-up agent. The retailer's distribution centrals function as semi depots. Here the manually received bottles are bar code registered and counted at a petimeter before being compacted. Similarly as for the RVMs, information about the number and type of bottles is transferred to Norsk Resirk. The already compacted and registered PET bottles from the RVMs are also stored at the semi depot.

To illustrate the recycling loop so far, the pictures below show the various operations returned PET bottles and aluminium cans go through before they end up at semi-depots or distribution centrals. Please note that "PANT" in the figure refer to deposit.



Consumer returns to the Store
Store keeper check

Full plastic bags are closed with a plastic clip. Labeled with bar

Combination, wholesaler (99%) and 3. Party (1%)

Bottles and cans are counted and registered in the Petimeter.
Deposit information transferred to Resirk in same format as for RVMs.

Figure 2.3: Parts of the recycling loop for PET bottles life cycle; from used bottles to storage at semi-depot.

Baling at depot

PET bottles from all the semi-depots are transported to baling at Norsk Resirk's main depot or to a regional joint venture partner. Here wrongly sorted cans are removed by magnets, whereas other undesired substances are manually sorted at a conveyer belt, before bottles are punctured, high compacted and bundled into PET bales. These 300-400 kg and 1.5-3 m^3 rectangular bales are transported by trucks to a reclaimer. The prices of delivered bales could, dependent on bottle type, colour, sorting quality and market price for primary and secondary PET resin, vary from €0 - 300 €/metric tonne (PCI 2000-2004).

It is not possible to acquire data of the quality of every PET bale produced at Norsk Resirk's depots in Norway. Even though the reclaimers make quality requirements for PET bales, by themselves or together with the supplier, they only have resources to have a rough look at the quality of the received PET bales. Nor is Norsk Resirk controlling the quality thoroughly. They do, however, carry out so-called pick analysis[3] to check the colour mix and presence of non-PET in the bales from time to time is.

It is possible to identify the mix of the PET bottles in the bale since the RVMs and petimeters have registered every bottle returned, and since these are the same bottles that end up in the (average) PET bale. According to Norsk Resirk there is no loss of PET material from bottles are returned by the consumer to when the PET bales are delivered at the reclaimer. Norsk Resirk has information about the colour of the bottles that are participating in the system, and to certain agree what closures, label type and label adhesive these bottles have. However, it is not possible to identify the amount of non-PET units in the bale using this method.

After delivering the PET bales to the reclaimer, Norsk Resirk is no longer responsible for the material- and cash flow of the PET bottles. The PET bales can hence be defined as an intermediate product of the Resirk/PET system.

Figure 2.4 below shows that the PET bottles are transferred from semi-depot to sorting and baling at main depots. The map illustrates where in Norway the depots are located as well as how large a part of the overall volume of returned bottles that are treated at each of the depots. For example we can see there are four semi-depots and one main depot covering Oslo and the eastern part of Norway. This main depot covers 60 % of the returned Norwegian bottles.

Reclaiming

The reclaimer is a factory that turns used bottles into reclaimed PET flakes (RPET), the secondary raw material which is used to produce 100 % recycled products or products containing a certain fraction of reclaimed material. The first thing the reclaimer has to do is to de-bale the bundles. To make sure the final product will be as pure as possible, the de-baled bottles are once again sorted - manually or automatically - before they are pre-washed and are shredded into flakes. The flakes are washed and dried in turn, and then they are stocked and sold. It is when the flakes are used by the buyer that the actual recycling sets into action: the flakes, the secondary raw material, are melted then manufactured into a new product. The price of the PET flakes is, as for PET bales, dependent on quality and market and varies between € 400-800 €/metric tonne (PCI 2000-2004). The price of RPET flake is normally between 60-80 % of the price of primary (virgin) PET resin (PCI 2000-2004). The PET bottles in the Resirk system was mainly reclaimed at the Danish company Expladan during the 2000-2003 period.

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[3] When doing a pick analysis each and every unit in a PET bale is registered. Thereafter the percentage of coloured bottles, bottles with other important characteristics, cans and other non-PET units are calculated.

Figure 2.4: Baling of PET bottles in Norway

Recycling at end user markets

RPET flakes or granulates melted from RPET flakes are recycled into various types of products. The application area depends on quality of the secondary material as well the demand within the various end-user sectors. In every sector the RPET flakes have to compete with primary material as well other secondary raw materials. In 2002 1,108,000 metric tonnes of RPET flakes were produced in Europe and delivered to end-users world wide, particularly for fibre production in Asia. The table below shows how much each type of end-user bought (PCI July 2003)

End-user market	**2002 [tonnes]**
Fibre production	835,000
Bottles for beverage and other food	79,000
Strapping	75,000
Sheets	58,000
Bottles, non-food	31,000
Moulding	17,000
Other purposes	13,000
Total	1,108,000

Table 2.2: End user market for RPET flake

As we can see, by far the most RPET flakes are applied in the fibre industry, mainly for production of clothes. However it is interesting to see that the bottle industry is increasingly interested in using secondary raw materials. Raw materials for use in the beverage and food industry (food grade PET resin in Figure 2.1 in Section 2.2) must be of extremely high quality to avoid any pollutants coming in contact with the beverages. So far only around 10-15 reclaimers worldwide are approved as suppliers of “bottle to bottle” quality.

Bottles not returned

For various reasons not all PET bottles are returned to retailers. Some are thrown into streets or outdoors, others are separated and placed in designated kerbside bins or drop off locations for plastic packaging, while many bottles are disposed, un-separated, together with other household waste. Sooner or later all these PET bottles end up at landfill or at incineration plants. Norsk Resirk does not pay any expenses for treatment of non-returned PET bottles.

3. Industrial ecology

By taking basis in one of the most known definition of industrial ecology, this chapter presents the industrial ecology perspectives of systems and life cycles, environmental and economic efficiency, as well as the perspective of development.

3.1. Introduction

As a PhD student at NTNU's industrial ecology programme, I find it natural to apply the interdisciplinary field of industrial ecology (IE) as a theoretical starting point in this thesis. According to Lifseth (1997), IE can be seen as the operational part of sustainable development, which is defined to be a "development which meets the needs of the present generations without compromising the ability of future generations to meet their own needs " WCED (1987). However, where sustainable development is concerned with questions related to environmental, societal and economical issues in a global perspective, the concept of IE seems to be restricted to understanding and improvement of environmental and economical issues in industrial societies.

The aim of IE is to design and re-design industrial systems, by using nature as a metaphor and model. Such an approach is based on the fact that flows of energy and materials in economies have many features analogous to similar flows in ecological systems, which was earlier called industrial metabolism (Ayres 1978, Ehrenfeld 2003). By striving towards a society based upon IE principles, less non-renewable resources will be depleted and less emissions and wastes will be released into the natural environment. For some, IE is a new, powerful analytical framework, for others it is a metaphor that leads to a new vocabulary for talking about and making sense of the world. In the latter sense, IE is paradigmatic in nature (Ehrenfeld 1997). Sagar and Frosch (1997) point out that IE is loosely used in literature, varying from the narrow outlook such as municipal waste collection to the broader perspective of social and environmental change at the global level. Another important distinction is whether IE should strive to be as objective as possible or whether normative elements should also be included. According to (Ehrenfeld 2003) the ecological metaphor of IE has produced two or more less separate set of practices:

- The objective side which seeks to acquire better understanding of industrial economies. Material flow analysis (MFA) and substance flow analysis (SFA) are examples of tools that are applied
- The normative side sees IE as a framework for designing more sustainable societies.

For more than a decade researchers and parts of industry have worked with IE. As mentioned above, there are several approaches to this field, and, consequently, there are also various definitions. I prefer to base my thesis on the perhaps most used definition of IE (Graedel and Allenby 1995):

> *Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system must be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital*

From this definition I would like to highlight three perspectives:

- System and life cycle perspective ("…it is a systems view which one seeks to optimize…")
- Environmental-economical perspective ("Factors to be optimized include resources, energy and capital")
- Development perspective ("…continued economic, cultural, and technological evolution")

In the following sections we will have a deeper look into each of these IE perspectives.

3.2. System and life cycle perspective

According to Graedel and Allenby (1995) industrial ecology requires that an industrial system must be view in such a way that one seeks to optimize the total material life cycles of the system. In this section we will have a look at the implication of such a system- and life cycle perspective.

3.2.1. System perspective

System definition
We should start by trying to define what a system is. According to Bossel (1999) "A system is a complex unity formed of many often diverse parts subject to a common plan or serving a common purpose". A more comprehensive definition from the same author is "A *system* is anything that is composed of system *elements* connected in a characteristic system *structure*. This configuration of system element allows it to perform specific system *functions* in its system *environment*. These functions can be interpreted as serving a distinct system *purpose*. The system *boundary* is permeable for *inputs* from and *outputs* to the environment. It identifies the system's *identity* and *autonomy*." see the figure below.

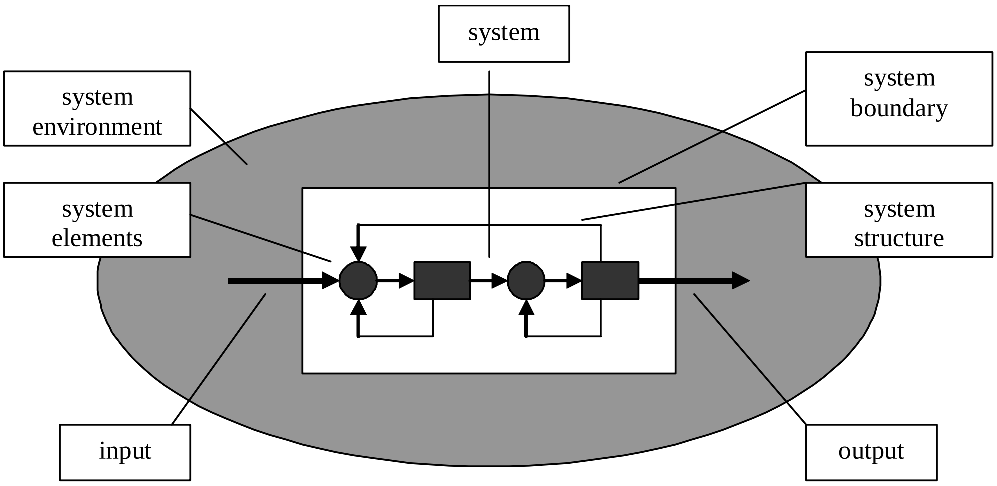

Figure 3.1: A system interacts with its system environment through system inputs and outputs (Bossel 1999)

Oliver et al (1997), who have written a book on system engineering, define system to be “a thing built from many other things, or components, which interact for a common purpose”. Moreover they state that to define a system an engineer must describe its *context, behaviour or purpose, and structure*. The structure of a system is the parts that it compromises and the relations among them, all system components, and how they are interconnected. When the behaviour of a system is described, scenarios of its use under a variety of conditions and the system’s response to the scenarios are considered. According to Oliver et al (1997), systems consisting of objects are often composed from other systems. Objects (with name, properties, task/action/function, inputs and outputs, connected) are built from other objects. Aggregation allows us to consider an object as a unit/system, ignoring its component parts, which indeed is a vast simplification, but nevertheless a condition for thinking of and working with systems. Alternatively, it allows us to consider an object as an assembly of parts, to think about how it is built (Oliver et al 1997). Another basic rule in system theory is that a given component part or sub-system is similar (with the same structure and behaviour) whether it is treated as a part of a system or whether it is analyzed as a system on its own (Checkland 1999, Oliver et al 1997).

Checkland, who has been working with *system thinking* and *system practice* for more than 30 years, states that “the central concept system embodies the idea of a set of elements connected together which form a whole, this sowing properties which are properties of the whole rather than properties of its components parts. The concept is an idea that the whole entity which under a range of conditions maintains its identity”

The system boundaries of Resirk comprise the *material flow* from used PET bottles to production of secondary raw material and heat, see Chapter 4.2.3 for exact definition. The Resirk system fulfills Bossel’s conditions (Bossel 1999) of being a system in the sense that it has *elements* (sorters, reverse vending machines, reclaimers etc.), which is connected in a *structure*. Moreover, the material based system boundary is permeable for *inputs* from (e.g. production and consumption system for PET bottles) and *outputs* (e.g.

emissions and new products) to the nature and corresponding product systems. This gives the Resirk system *identity* and *autonomy*. Another question, however, is to what extent the Resirk system "performs specific system functions in its environment" and whether "these functions serve a distinct function structure". One perspective could be that the Resirk system serves the function and purpose of transferring used PET bottles into raw material for new production. Other may argue that the function is essentially to get rid of PET bottle waste in an appropriate way. My definition of the Resirk system and its function is based on Norsk Resirk's mandate, and the eco-efficiency- and LCA literature, and represents a third way of looking at a function, see Chapter 4.2.3 for a definition of functional unit. This shows that perceived function and purpose in the recycling system may vary, dependent on the observer of the system, as Checkland (1999) states below. It should be mentioned that this is also the case when defining the system boundaries.

Characterization of systems

There seem to be many different systems, but how can they be distinguished and characterized? Bossel (1999) distinguishes between *human system*, which consist of individual development, s*ocial system* and *government system*; *support system* that includes *economic system* and *infrastructure system; and natural system*, which is the environment and resource system. According to Checkland (1999) four kinds of system typology are required: natural, designed physical, designed abstract, and human activity systems. He states that the concept human activity system is crucially different from the concept of natural and design systems. The latter, once they are manifest, "could not be other then they are", but human activity systems can be manifest only as perceptions by human actors who are free to attribute meaning to what they perceive. There will thus never be a single (testable) account of human activity systems, only a set of possible accounts are valid according to world view." Another way to categorize systems is to distinguish between *static-*, *metabolic*, *self-supporting, selective, protective, self-organising, non-isolated, self-producing, sentient and conscious systems* (Bossel 1999).

Systems and sub-systems

Now after we have described what a system is and what it consists of, it is hence time to look at how systems are connected to each other, and how a system interacts with its environment (the other systems). Bossel (1999) sees the human society as a complex adaptive system embedded in another complex adaptive system, the natural environment, on which it depends for support. He argues further that there are no isolated systems in the world and, moreover, that a system can only exist and prosper in its environment if its structure and functions are adapted to the environment. Bossel sees the world (which he argues needs to be sustainable) as the ultimate system and that natural systems, support systems, and human systems are sub-systems. Each of these systems has again their sub-system and so on. He states for example that a waste disposal system is a sub-system of the infrastructure system, which again is a part of the support system. He argues further that these systems are connected to other systems, such as social systems. As far as I can see, this way of distinguishing systems could also be appropriate for the Resirk/PET system, a system Norsk Resirk has characterized as a "deposit and recycling system". The transformation of used PET bottle to valuable material and heat is the main system, while human and natural systems are prerequisites for this system.

According to Checkland (1999) Optner (1965) look upon an organization as a system with functional sub-system concerned with production, marketing, finance, human resources etc. Checkland (1999) has an interesting illustration of systems on different levels. He distinguishes between *wider systems, systems, and sub-systems* and states that the choice of system is made by the *observer*. If level 3 is "system" then for that observer 2 is a wider system and 4 is sub-system level. Thus system thinking ensures thinking at three levels

If we for example look at the Resirk system it may be that Norsk Resirk sees this system as the system, the RVM operation system as the sub-system, and the European system for collection and recycling of PET bottles as the wider system. The RVM supplier Tomra Systems, on the other hand, may see the RVM system as the system, the bar code reader in the RVM as the sub system, and the Resirk system as the wider system. Hence, the system defined is always dependent on the observer's system perspective.

In social science one often applies an analytical distinction between micro and macro. Micro is defined analytically to be the elementary objects and processes we study, while macro is the "overhanging" framework or system we study these objects within (Guneriussen 1999). For example: the RVM (micro) could be studied within the framework of the Resirk system (macro). In social science the distinction between actor and structure is the usual way to discuss the micro-macro perspective.

Relation between actor, structure and system.

Are the human actors creating the society's system structure or are individual actions created by the structure? In social science this has, for a very long time, been a widely analyzed and discussed issue. Guneriussen (1999) has written an excellent book on this subject and from this book I will give a brief presentation of some of the most important approaches to this question. The classic economic theorist Adam Smith (1776) argued that the actors behave solely selfishly and are only concerned with maximizing their own benefit and, furthermore, that interference between all individualists generates the structural conditions in society. Marx, on the other hand, stated that there is a determining power in material conditions and economic structural aspects within society. The individuals' action is thus determined by technical-, economic and ideological aspects of society. In Durkheim's (1895) functionalism, which was the precursor to the social system theory, society is perceived as an "above-individual", objective reality and power that decide the individuals' activities, independent of their subjective purposes and ideas. The system theorist Luhmann (1989) goes even further, claiming that sociology is about ocieties' systems and their sub-systems. Actors exist but they have no influence on the system structures. Systems, on the other hand, are influenced by and connected to other (closed) systems, through "structural connections". Human beings are only considered to be "appendix" to objective self-regulation systems with given functions. Systems communicate, observe, make distinctions between the systems and the environment (other systems).

"Softer" system theory, represented by among others Bailey (1994), includes notions such as action, actor consciousness, language and institutions. According to Bailey, human beings can communicate and move in and between system borders. Bonds between companies and networks don't only occur solely in the economic systems, these are important activities in other systems as well. Another theory on the relation between actor and structure is developed by Giddens (1984). In his "structuration theory" structures and systems continuously are produced and re-produced through (mostly intended) repetitive human activities. Giddens' structure is hence both a condition for action and a product of action.

3.2.2. Life cycle system perspective

A much applied system perspective among industrial producers is the life cycle system perspective. Often such a perspective implies that a product's total impact on all life cycle stages between extraction of raw material and waste management are considered. Traditionally, industrial producers had a system perspective which was restricted to the production plant they owned. A beverage producer would for example be solely occupied with costs and benefits of what is going on within the walls of the bottling plant. However, during the last decade decision makers in industrial societies have to an increasing degree, been concerned about costs and benefits of larger parts of the life cycle of the product they produce or contribute to produce (Bohne 2005). So, if you are a beverage producer and wish to have a complete life cycle approach to the way you do business, you should be concerned about the life cycle costs and -benefits of the beverage you are producing as well of the life cycle of the bottles applied to distribute, preserve and serve the beverage. In the case of the PET bottles, impacts from extraction of oil and gas, production of PET resin, blow-moulding of PET bottles, filling, distribution, consumption and waste management, including potential re-use, recycling, incineration or landfill, should all be taken into account.

Ideally one should always strive towards a complete life cycle system perspective, however, there are situations when it may be more appropriate to have a more narrow system perspective. A municipality taking care of all separated waste fractions from the households in the municipality may, for example, have a life cycle perspective in the sense that it will be concerned about bringing the waste into new life by recycling. However, the municipality will not be able to follow and influence the design and production of all products in order to make them more suitable for recycling. Hence, it would perhaps be more correct to say that the municipality has a waste management system perspective.

According to White and McDougall (2003) there are two general requirements for more sustainable solid waste management:

1. the production of less waste in the first instance and
2. an environmentally effective, economically efficient and socially acceptable way to deal with the solid waste that is still produced

Figure 3.2 below shows the relation between various perspectives. When having a life cycle perspective, both production, use of the product, as well as waste management is concerned. Examples of sub-system perspectives presented in the figure are the production perspective, recycling perspective and the waste management perspective. As for Norsk Resirk it could be argued that they have a recycling perspective since they are not concerned about used PET bottles that are not returned and hence incinerated or deposited at landfills. However, as we will see in chapter 4.2.3, I have defined the function and system boundary of the Resirk system, based on the perspective of Norsk Resirk, to include the waste management options of incineration and landfill.

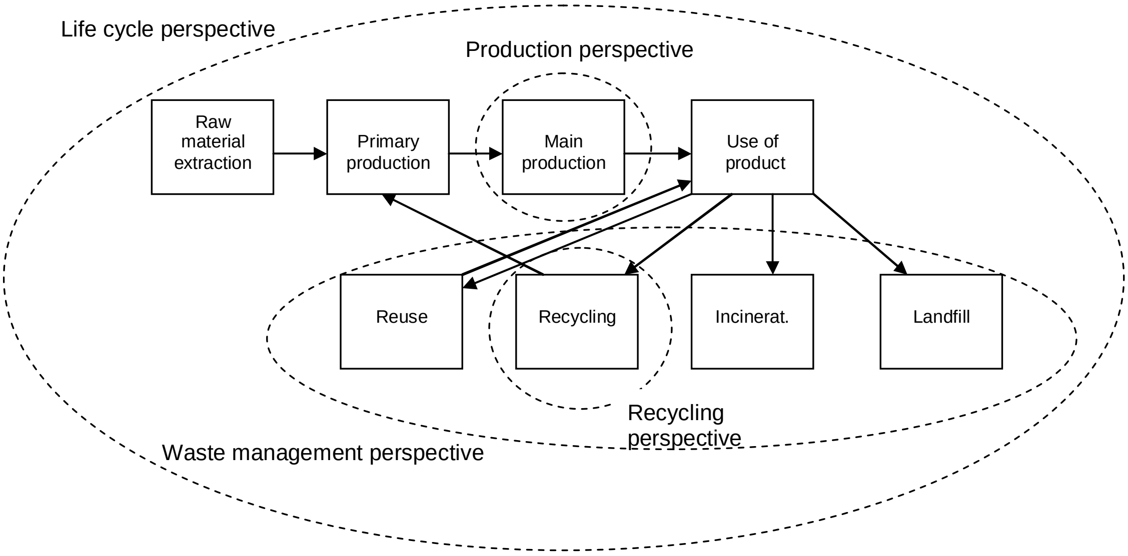

Figure 3.2: Life cycle-, production- , waste management-, and recycling perspective

After having focused on various systems, including life cycle systems, it is time to look at what to measure in the systems.

3.3. Environmental - economical perspective

According to the IE definition by Graedel and Allenby (1995), a system view implies that material's life cycle should be optimized on the basis of resources, energy, and capital. Hence, focus on environmental- and economical performance of systems are central. In this section I will present a framework for quantification of eco-efficiency of systems. As we saw in chapter 1, the mandate of producer responsible organizers (PROs) is to ensure that a recycling and waste management system is organized and operated in a sound environmental- and economical manner. From such a perspective the challenge is therefore to propose an eco-efficiency framework appropriate to conduct analysis which could answer whether this is the case.

The framework is suggested on the basis of the flexible eco-efficiency approach for companies and organizations, to be presented in section 3.3.1, in combination with the more rigid requirements in the methods of life cycle assessment and life cycle costing, which will be presented in 3.3.2 and 3.3.3, respectively. This suggested framework will be applied in chapter 4.2 to carry out methodological choices for the analysis of the eco-efficiency system of Resirk/PET, which will be conducted in chapter 5.1.

3.3.1. Eco-efficiency

Eco-efficiency approaches

Eco-efficiency was popularized in 1992 in the book 'Changing Course' by Stephan Schmidheiny with the World Business Council for Sustainable Development (WBCSD) (Schmidheiny 1992). Since then this concept and indicators have been further developed and applied by WBCSD (1996, 2000, 2003), Verfaille and Bidwell (2000) and others such as Fussler (1996), OECD (1998), the Global Reporting Initiative (1998), the Norwegian Research Council (2000) , Eggels et al (2000), NRTEE (2001), Salling et al (2002), Jenseit et al (2003), Huismann (2003), UNCTAD (2004) and Bohne (2005) Today a growing number of companies, organizations, governments, consultants, and academics are using and interpreting eco-efficiency for their own projects and benefit.

Eco-efficiency is perceived by many to be the business link to sustainable development (DeSimone and Popoff 2000). The most well known definition of eco-efficiency is provided by World Business Council for Development (WBCSD 1996):

> *Eco-efficiency is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impact and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity.*

As we can see from this rather ambitious definition, emphasis is put on how the economical- and environmental performance of goods and services can be improved in a life cycle perspective. While the WBCSD focuses mainly on how companies and organizations can work towards being more sustainable, “doing more with less”, the OECD (1998) has taken a more governmental approach and has identified policies that can encourage innovation by firms and communities, and provide an economy-wide framework of economic and regulatory incentives for the adoption of more sustainable patterns of production and consumption. The OECD has called eco-efficiency *the efficiency with which ecological resources are used to meet human needs.*

The text above indicates that the eco-efficiency can be understood and applied in various ways. Verfaille and Bidwell (2000) try to sum up by arguing that eco-efficiency offers an open and flexible approach, focusing on *giving needed information for decision making* by taking both economic and environmental issues into account. The Norwegian Research Council (2000) has made an interesting distinction between the various approaches by claiming that eco-efficiency can be understood as i) a *concept or strategy* to improve the environmental and economic performance of a company or a nation, and ii) as a way of measuring this performance by means of *indicators*. Hence, strategies and indicators are closely connected. In our case Norsk Resirk may for instance measure the eco-efficiency of waste management of used PET bottles by use of eco-efficiency indicators, and thereafter develop strategies to improve the eco-efficiency. Indicators may be used again at a later stage to check whether implemented strategies have succeeded to improve the Resirk/PET system’s eco-efficiency.

Eco-efficiency as strategy

Governments, companies, organizations, and other actors who are concerned about eco-efficiency develop strategies to improve the “efficiency with which environmental resources are used to meet human needs”. Many firms in OECD countries have developed strategies that involve: - developing goals to reduce resource use and pollutant release while improving customer service; - working towards the goals through innovation in technology, practices, and ways of thinking; and - designing indicators to monitor progress (OECD 1998)

The WBCSD sees eco-efficiency as a management philosophy that focuses on *opportunities* and encourages business to search for environmental improvements which yield parallel economic benefits (WBCSD 2000). According to the WBCSD (2003) companies can strive towards eco-efficiency by focusing on:

- Optimized processes
- Waste recycling
- Eco-innovation
- New services
- Networks and virtual organizations

Moreover, Verfaille and Bidwell (2000) have identified seven elements that business can use to improve their eco-efficiency:

- reduce material intensity
- reduce energy intensity

- reduce dispersion of toxic substances
- enhance recyclability
- maximize use of renewables
- extend product durability

As we can see there are many ways of improving eco-efficiency, and some of them involve focus on recycling: WBCSD (2003) mentions recycling of waste, while Verfaille and Bidwell (2000) put more emphasis on making goods suitable for recycling. In a PET bottle perspective, for example, it is hence both important to design the PET bottles in such a way that they are fully recyclable while at the same time making sure that collection-, transportation- and re-processing systems are in place so the bottles can be recycled into new products. In the following we will have a look at the indicators that among others, can give quantitative answer to what extent a strategy has succeeded in bringing in greater eco-efficiency or not.

Eco-efficiency as indicator(s)

Intuitively we all use indicators to monitor complex systems we generally are interested in or need to control. Indicators condense enormous complexity to a manageable amount of meaningful information, to a small set of observations informing our decisions and directing our actions (Bossel 1999). For example, we measure the temperature in ^{0}C, give the economic activity in the USA by the Dow Jones Index and present emissions of climate gases by kg CO_2-equivalents. According to Meadows (1998) indicators both arise from values (we measure what we care about) and create values (we care about what we measure). Most values are place- or culture-specific, others may be common to all humanity. According to Hertwich and Hammitt (2000) there exist no such things as value-free objective indicators. They state that an indicator is good if it supports the purpose of the analysis carried out and at the same time gives desired information for decision-making.

There are various opinions on how the eco-efficiency should be calculated in order to make it as scientific and applicable as possible. Some may have a strong scientific view and argue that the eco-efficiency have to be calculated as a ratio (s) of value added and (all) environmental impacts, while others, like Verfaille and Bidwell (2000), take a more pragmatic view and claim that reporting on the environmental and economic profile, by use of a limited number of indicators separately, because this will often provide a better basis of information for decision making. Moreover, as mentioned before, the WBCSD warns of producing excessive information. Only the most meaningful combinations, providing the most useful information for decision-making, should be used to measure eco-efficiency.

Eco-efficiency equations

Eco-efficiency is often expressed by the following equation, which merges value and ecological aspects into an efficiency ratio (WBCSD 1996):

$$Eco\text{-}efficiency = \frac{Product\ or\ service\ value}{Environmental\ influence}$$

Eco-efficiency can hence be considered as a ratio of an output divided by an input: the "output" being the value of products and services produced by a firm, a sector, or the economy as a whole, and the "input" being the sum of environmental influence generated by the firm, sector or economy (OECD 1998). In the case of the Resirk/PET system the output can for example be defined to be the secondary PET raw material produced, whereas the input is the environmental costs and benefits of producing the secondary raw material from used PET bottles. As we will see below, both "product or service value", which measures economic influence, as well as "environmental influence" can be expressed with various indicators.

Since eco-efficiency is meant to be flexible and pragmatic, many authors argue that measuring eco-efficiency is not restricted to apply the equation above. In a large eco-efficiency conference arranged in Leiden in April 2004[4], the organisers welcomed the participants by stating the following:

> "By indicating the cost per unit of environmental improvement, or equivalently the value creation as related to environmental costs, one may discern between more and less eco-efficient forms of economic growth and environmental improvement."

As we can see, the conference organisers opened up for having different types of "environmental influence" indicators as denominator and various "Product or service value" indicators as numerator in the eco-efficiency ratio. However, if highest possible eco-efficiency, i.e. highest possible numerator and lowest possible denominator is preferable, it will in some situations be required to turn the ratio. For example in the case of recycling, where the environmental benefits often are larger than the environmental disadvantages and where the aim is to have the lowest possible cost, an alternative ratio for eco-efficiency can be defined as:

$$Eco\text{-}efficiency \equiv \frac{Environmental\ influence}{Economic\ influence} \equiv \frac{Environmental\ influence}{Cost}$$

In addition to be quantified as a ratio, environmental influence and cost can also be given as separate indicators.

Purpose of eco-efficiency

The aim with eco-efficiency indicators is first and foremost to provide decision makers with useful information. According to the WBCSD (2000) eco-efficiency indicators are a

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[4] Conference web page: **http://www.eco-efficiency-conf.org/**

useful tool for monitoring and reporting performance, and for helping the firm's communication and dialogue with each stakeholder. It could ensure more efficient decision making internally at the same time as fulfilling stakeholder requirements. However, in order to make changes, it is not enough to just measure eco-efficiency indicators based on strategies developed. According to UNCTAD (2004) indicators are only relevant when they influence the decisions of users by helping them to evaluate past, present or future events, or by correcting or confirming their past evaluations. However, it must be noted that the concept of eco-efficiency is also to an increasing degree, applied in a research context, see for example theses from Bohne (2005) and Huismann (2003). In my thesis the concept of eco-efficiency is applied to support the purpose of the analysis, i.e. to see how the cost and environmental efficiency of the Resirk/PET system for PET bottles has changed since it was established in 2000 and, moreover, to find the highest contributing factors to this change. If the eco-efficiency indicators chosen are able to contribute to this purpose, I would argue that they have served their purpose and hence can be regarded as successful.

Application areas

Eco-efficiency information can be used for several purposes for a decision maker. If we again have a look at the Resirk/PET system I would argue that there are at least three potential application areas for eco-efficiency indicators; comparison with alternative- or other facility options and waste management systems, external credibility, and internal improvements (WBCSD 2000).

The economic and environmental influence of a system with waste management facilities that give a certain recycling rate, can for example be compared to a situation with alternative waste management solutions which may give a higher or lower recycling rate. We have seen several studies of systems based on extended producer responsibility, especially for packaging, which have been carried out by researchers or consultants in order to define optimum recycling rates (Eggels et al 2000), or to compare recycling with other waste management options (Lerche Raadal et al 2001), or eventually, to compare various packaging types (Lerche Raadal et al 2003).

Application of eco-efficiency indicators could also have a central role to play when it comes to external credibility. The consumers are maybe the most important actors in a recycling system. If the consumers don't take their bottles or paper back to the collection points after use, the organizer of the waste management system has no input material to their systems, and, hence, no secondary materials to be recycled are produced. Moreover, the recycling rate will be lower than agreed with the Government. The consumers must be motivated to bring their end-of-life product back into the loop. One important condition for this is that the consumers must be assured that the recycling they are taking part in is environmentally preferable as well economically feasible. Hence, communication of understandable eco-efficiency results could be useful. Another important receiver of such a message is the national Government which was responsible for establishing the recycling loop in the first place, and which also has the ability to eliminate the system if it is not functioning well. Other important stakeholders that may be interested in following measurements by using eco-efficiency indicators are the producers of packaging and beverage/food, importers and trade which normally pay fees to keep the system going (in the last resort it is the consumers who buy the wrapped up product who have to pay). To conclude, all the actors involved require value for the money and the effort they put into the recycling loop. Moreover, the margins in the recycling business are small and a strong focus on costs reduction and increased revenues is maybe even more important here compared to other businesses. Eco-efficiency indicators could provide the stakeholders with information whether or not this is the case.

Internal improvement is a third way of using eco-efficiency indicators. The analysis by use of the indicators can identify where in the recycling system the improvement potentials are. Trend data are important so that changes in performance over time or compared to reference point can be assessed. Data can be expressed as absolute figures, eco-efficiency ratios, indexed to a selected year, or expressed relative to a projected goal. Based on the quantification of eco-efficiency by indicators, challenges can be identified. Thereafter eco-efficiency targets can be set, strategies can be made, implementation of initiatives can be carried out, before measuring progress toward achieving eco-efficiency are analyzed. Hence, as mentioned before, strategies and indicators for eco-efficiency are closely connected

Indicator principles

As mentioned above, the eco-efficiency indicators must serve the purpose of an analysis or an evaluation. Hence, it is not for the decision maker or researcher to just pick any indicators.

According to the Verfaille and Bidwell (2000), indicators should be based on a basic set of principles that define how they will be selected and used. The indicators should:

- be relevant and meaningful with respect to protecting the environment and human health and/or improving the quality of life
- inform decision making to improve the performance of the organization
- recognize the inherent diversity of business
- support benchmarking and monitoring over time
- be clearly defined, measurable, transparent and verifiable
- be understandable and meaningful to identified stakeholders
- be based on an overall evaluation of a company’s operations, products and services, especially focusing on all those areas that are of direct management control
- also recognize relevant and meaningful issues related to upstream (e.g. suppliers) and downstream (e.g. use) aspects of a company’s activities

Eco-efficiency at various levels

Even though eco-efficiency indicators have often been developed and applied from a company perspective, strategies and indicators could also be applied at other levels as well. UNCTAD (2004) are distinguishing between eco-efficiency at three levels: national and supranational level, sector level (household, industry, agriculture etc), and company or organization level

With respect to measuring eco-efficiency when having a company/organization perspective, eco-efficiency may be measured for the company/organization as a whole, for the activities and processes they are involved in or for one or several of the products they (contribute to) produce.

An important discussion within the eco-efficiency community, particularly when it comes to measurements on the company/organization level, is what to include in the environmental- and economical account. What should the system's measurable borders be? Both UNCTAD (2004) and WBCSD (2000) recommend a focus on what is under management control of the company or organization. Upstream and downstream activities may be useful to include but very often it will rather complicate the picture (UNCTAD 2004) and Verfaille and Bidwell (2000) opens up for including product cycles but experience so far is mainly limited to eco-efficiency measurements of production sites and one or two upstream activities. There have probably been three main reasons for not including upstream and downstream activities in company's eco-efficiency initiatives: the problem of data acquisition, the management problem, and the issue of relevance.

A nation, municipality, company organization will probably not have access to all the data needed to conduct a complete eco-efficiency analysis. It may be particularly difficult to acquire cost and revenue data from companies. In addition, it is often very time consuming to acquire emissions data from production sites and processes. Many companies and organizations feel that they don't have the opportunity to improve activities upstream, operated by other actors, even in those cases where environmental and economic data may be acquired. This is again particularly the case for indicators of economic performance. Finally, companies and organizations think that emissions and costs "far away" upstream and downstream are somebody else's problem.

From a broader sustainability perspective, one may argue that companies should have access to all data and that they should have the product cycles of (all) their product on top of their agenda. However, such a requirement would be perceived as too resource consuming for a company or an organization, and could probably rather lead to a situation where companies find it too cumbersome and choose to not implement the eco-efficiency thinking at all.

WBCSD's general applicable and business specific indicators

Many authors and institutions have suggested applicable indicators for various types of decision-makers, see for example UNCTAD (2004). Verfaille and Bidwell (2000) have made an indicator framework for World Business Council for Sustainable Development (WBCSD), which they argue can be used by any business to measure progress toward economic and environmental sustainability. Through testing together with 23 companies, they have developed "generally applicable" and "business specific indicators". The generally applicable indicators, which are argued to be applicable to virtually all businesses, should measure products, services, processes, activities or companies that are "under direct management control". Proposed indicators are as follows:

Indicators for product or service value:
- Quantity of product/service produced or sold
- Net sales of a product or company

Indicators for environmental influence:
- Energy consumption
- Water consumption
- Material consumption
- Greenhouse gas emissions
- Ozone depleting substance emissions

In addition to the "generally applicable indicators", the WBCSD also proposes that "business specific indicators" should be developed if more information on environmental and/or economic performance is needed. These indicators should be developed to describe all relevant and meaningful aspects for a company, and will be dependent on the sector and type of business (Verfaille and Bidwell 2000).

Eco-efficiency of waste management systems

Bohne (2005), Husiman (2003) and Salling et al (2002) have all found that economic performance of waste management systems with a substantial element of recycling should be expressed by cost of the recycling loop or the whole waste management system, whereas environmental efficiency can be expressed by the environmental impact or – burden of the system. All the abovementioned authors express eco-efficiency indicators in a so-called portfolio diagram.

Jenseit et al (2003) have carried out an eco-efficiency study of recovery and recycling options of plastic parts, and present the cost on the x-axis and relative environmental burden on the y-axis, see Figure 3.3 below. The environmental burden- and cost average of all the systems or scenarios studied is set to a value of 1, which is displayed at the centre of the portfolio. Thereafter all the systems are plotted in relation to this average.

The most eco-efficient scenario (illustrated by the blue rectangular plot) is found on top right hand side of diagram, where the cost as well as the environmental burden is at the lowest. In the figure the environmental burden and relative cost are considered equally important. Hence, other scenarios, given by the six bullet points placed on a 45^0 slope, have the same eco-efficiency. The yellow bullet solution gives for example lower cost than the pink bullet solution. However, since the environmental burden for the pink one is equivalently lower, the eco-efficiency is the same for both solutions. However, it should be mentioned that there is room for flexibility; so if the decision maker considers cost to be more important than environmental burden, the yellow bullet, which has lowest cost, would be preferably to the pink one.

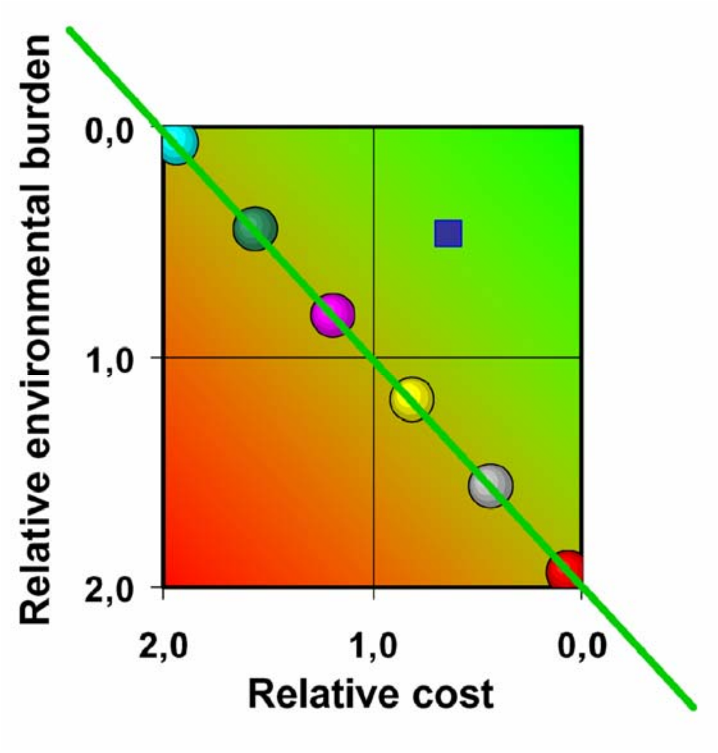

Figure 3.3: Example of an eco-efficiency portfolio diagram

As we can see in Figure 3.3 above all solutions can be compared to a reference scenario (in this case the average eco-efficiency of all the solutions). However, a portfolio diagram can also be applied to illustrate eco-efficiency if absolute numbers are preferably to report. In Figure 3.4 below the eco-efficiency of four different scenarios are given. Note that highest possible negative value for environmental influence and lowest possible cost is optimal from an eco-efficeint point of view.

Solution no. 4 has the highest eco-efficiency since it represents largest negative (avoided) emissions and the second lowest cost (only no. 3 has lower cost), while no. 1 has the lowest eco-efficiency since this solution has, by far, lowest environmental gain and second highest cost.

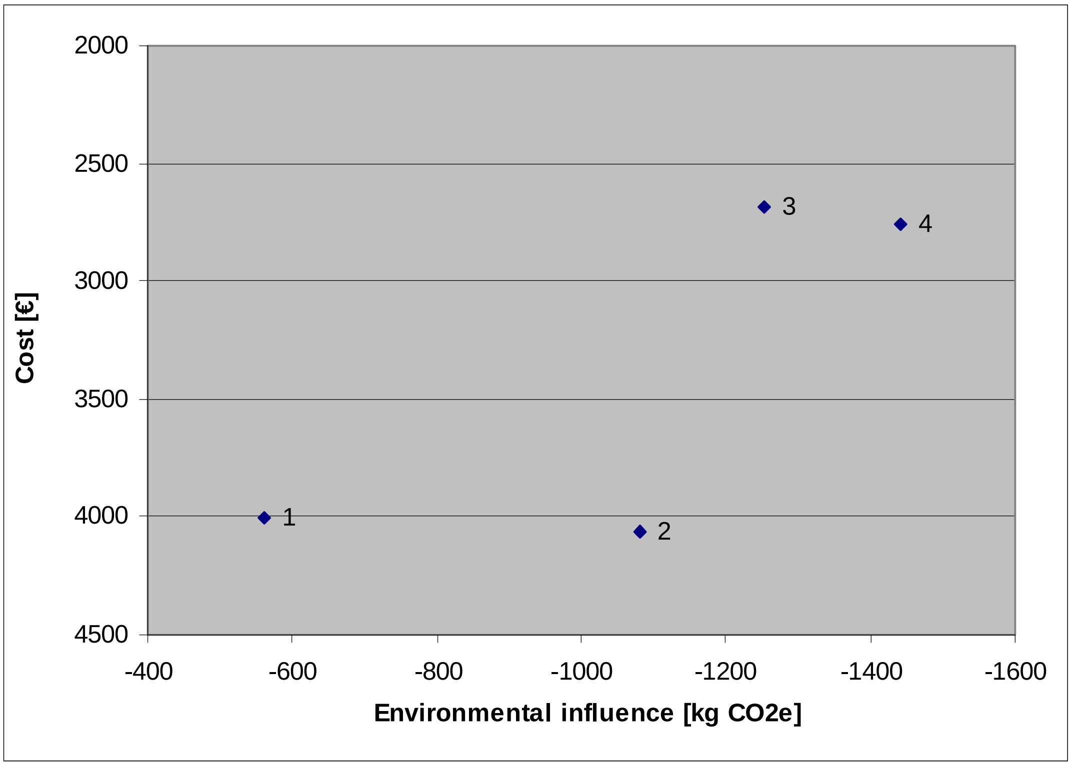

Figure 3.4: Example of eco-efficiency of waste management shown in portfolio diagram

Critiques towards eco-efficiency

Before leaving the concept of eco-efficiency for now, some of the critiques towards eco-efficiency should be presented.

> "It is important to understand that eco-efficiency is not limited simply to making incremental efficiency improvements in existing practices and habits. That is much too narrow a view. On the contrary, eco-efficiency should stimulate creativity and innovation in the search for new ways of doing things. Nor is eco-efficiency limited to areas within a company's boundaries, such as in manufacturing and plant management. It is also valid for activities upstream and downstream of a manufacturer and involves the supply and product value-chains. Eco-efficiency has moved from being concerned with making resource savings and preventing pollution in manufacturing industries to becoming a driver for innovation and competitiveness".

Despite these promising words put together by WBCSD (2003), the concept of eco-efficiency has through the last decade, received some criticism, in particular from academics. It does not include the social dimension of sustainability (Opoku 2005), the importance of eco-sufficiency is left out (Lamvik 2001), and eco-efficiency is only loosely coupled to ecosystem dynamic behaviour (Ehrenfeld 2003) which are all highly interesting arguments. The problem is however, that they are based on an assumption that the concept of eco-efficiency has the same level of ambitions as the concept of sustainable development where the abovementioned issues are central. Eco-efficiency may be criticized for not being sufficient to reach sustainable development. However, as the ambition of eco-efficiency is limited to be a contribution towards sustainable development, the critique against eco-efficiency is inaccurate. It would be more precise to criticize companies or organizations because they use eco-efficiency tools instead of focusing on the wider concept of sustainable development.

Another interesting argument on the use of eco-efficiency is the claimed lack of real effects of eco-efficiency improvements. In order to obtain real effects, they argue that the focus should rather be placed on *eco-effectiveness*. According to McDonough and Braungart (1998) eco-efficiency, which among other things focuses on recycling of unnecessary products, is neither new nor radical. They address the need for more fundamental changes. Eco-efficiency does not go beyond improving existing solutions, only incremental changes of current products, services and activities are offered, they argue. Another problem is that the borders of the system analyzed in many cases are made so small that anything can be claimed to be optimized (O’Rourke et al 1996). The following example of car transport in a city may illustrate the point of lack of willingness or ability to go beyond current practice and defined system borders. The costs of producing cars have decreased during the last twenty years, and in the same time period the emissions per car produced per km driving of these cars have been reduced significantly. Moreover, cars are to a larger degree than before recycled into new cars or other products. Hence, it can easily be shown that the eco-efficiency of many car types has increased considerably. These changes have been done through the improvement of an existing solution (the car as a mean of transport), as well as within the same system borders (the product system of the car).

Are the critiques then wrong? They will probably answer such a question by claiming that the eco-efficiency of most single cars has improved, but that that this improvement has been out weighed by the increased numbers of cars on the roads. They may draw the system borders around this city and argue that the eco-effectiveness of the transport sector in a big city has worsened. Cleaner and more efficient cars are not the solution to the pollution problems in this city, one has to re-think and find alternative transport solution than mainly cars, they may argue. Or as Hanssen (2001) puts it; functional efficiency (eco-effectiveness) should replace the current practice of striving towards technical efficiency (eco-efficiency). Again I would argue that this is not a valid argument of eco-efficiency as such, it is rather a critique on how it is applied. There are no restrictions in the concept of eco-efficiency towards having a “transport in the city” perspective instead of a “car” perspective.

As we have seen various perspectives can be a basis for eco-efficiency calculations. However, as mentioned before preparation and use of eco-efficiency indicators should reflect the perspective of the main decision-maker in the system studied. There are far too many examples on indicators that are too ambitious and/or too general perspective and hence not applicable for the user. The main point is that indicator proposed should be possible to use within the organization, or by the researcher, while being related to the perspective of the decision-maker. If this purpose is not fulfilled, and the nature/type of the indicator is to blame, the indicators have failed. Critiques may argue that such an approach will cause a too narrow (sustainability) perspective. However, to put it the other way around, if the decision-maker's perspective is narrow there is no reason to believe that indicators will broaden this perspective.

In the next sections I will try to narrow the eco-efficiency perspective by including life cycle assessment and life cycle costing. The emphasis will be put on product systems and waste management systems.

3.3.2. Life cycle assessment (LCA) and Life cycle costing (LCC)

Life cycle assessment (LCA) and life cycle costing (LCC) are the two most important tools within the concept of life cycle management (Ehrenfeld 2003). They are both tools within the system analysis family.

LCA

When using the method of LCA a product or service's environmental impact of the whole life cycle, from raw material extraction to final disposal, is examined. LCA has developed rapidly since it was established in the early 1990s and has reached a certain level of harmonization and standardization: The International Standardization Organization (ISO) has developed the ISO 14040s standard for LCA, Guinee et al (2002) have made a handbook on LCA, whereas the Society of Environmental Toxicology and Chemistry (SETAC) [5] has been very active in the field of development and standardization through its various working groups and conferences on LCA.

ISO has made a framework which consists of four phases of how to perform an LCA. In phase 1 the *goal and scope* of the LCA study is defined (ISO 14040 1997). In phase 2, the life cycle *inventory* analysis is performed by identification of all processes and collection of input and output data which are adjusted to the functional unit (ISO 14041 1998). Phase 3 consists of the life cycle *impact analysis* aimed at understanding the magnitude and significance of potential impacts of a products system (ISO 14042 2000). There are different life impact assessment methods available. For a comparison of the outcome of a study if using three of the most known methods, EDIP97, CML2001 and Eco-indicator 99, see Dreyer et al (2003). In the fourth and final phase, the interpretation phase, the findings from the inventory analysis and the impact assessment are combined together to *reach conclusions* and recommendations consistent with the goal and scope of the study (ISO 14043 2000). However, it is important to emphasize that the LCA should not be carried out in a too stringent way. According to Finnveden et al (2000) LCA is an iterative process, where information revealed in one phase could be applied to change decisions taken in an earlier phase.

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[5] See web page: www.setac.org

LCC

According to Norris (2001) it is often not sufficient to take environmental considerations into account when evaluating products. Information about economic consequences is often also required and desirable to be included. Norris argues that the traditional separation of LCA from economic analysis, and the trade-offs between them, has limited LCA's influence and relevance for decision-making.

But where to start if a decision maker wants information of both the environmental- and economical impact? While UNCTAD (2004) argues that "the financial accounting framework can serve as a valuable starting point in formulating the respective systems for environmental elements and items", I will turn it the other way around and suggest, as does the SETAC Europe Working group on LCC (Rebitzer and Seuring 2003), that the standardized method of life cycle assessment could contribute on how to quantify costs. This is often referred to as life cycle costing (LCC)

LCC is a method for calculation of the total cost of a product or service induced through its life cycle. There are several approaches to- and definitions of LCC. One is suggested by the SETAC-Europe Working Group on LCC (Rebitzer and Hunkeler 2003):

> *"LCC is an assessment of all costs associated with the life cycle of a product that are directly covered by one or more of the actors in the product life cycle (supplier, producer, user/consumer, EOL-actor) with complementary inclusion of externalities that are anticipated to be internalized in the decision-relevant future".*

From this definition we can see that externalities, such as for example emission of greenhouse gases, are recommended to be included when calculating life cycle cost. However, if these emissions already are included in parallel analysis of environmental influence, there is no reason to double count them by including them in the quantification of economic influence as well.

The SETAC working group distinguishes between four main types of LCC; Cost benefit analysis, budget LCC, managerial accounting, and LCA-type LCC which is the one applied in this thesis. Moreover they have identified nine various methods within the budget LCC category, eco-efficiency being on of them. In order to clarify the differences between variants, and to choose between most appropriate methods for analysis four basic questions should be answered, see Table 3.1 below

Dimensions	**Questions**	**Examples**
Cost categories	Which costs will be included?	Budget cost, personnel cost
Cost bearers	Whose costs will be included?	Producer, society
Cost models	How are the effects quantified?	Steady state, quasi-dynamic
Cost aggregation	How are the results aggregated?	Average yearly cost, NPV

Table 3.1: Various approaches to LCC

In order to make LCC compatible with the ISO steps for LCA (ISO 14040 - ISO 14043), SETAC (2004) has suggested including the following when carrying out the steps:

1. Goal and scope definition: for cost aspects including a specification of cost categories, the set up of cost modeling, and ways of cost aggregation
2. Inventory analysis (LCI): including system modeling, data collection, and cost profile development.
3. Impact assessment (LCIA): including the cost analysis to the analysis of environmental effects.
4. Interpretation, including the evaluation of alternatives as to their contribution to sustainability.

Use of LCA and LCC in waste management studies

LCA has mainly been developed to analyze material and products from cradle to grave, but according to Finnveden (1999) and Ekvall and Tillmann (1997), LCA can also be applied to evaluate waste management systems. In the definition of LCA, the term 'product' includes not only product systems but can also include waste-management systems. Although most studies of waste management systems have been conducted by LCA, cost related studies are also carried out to an increasing degree, see for example (Lerche Raadal et al 2001, Werner and Richter 2000, Salling et al 2002, Huismann 2003, Bohne 2005).

According to White and McDougall (2003) a 'product life cycle inventory (LCI)' can be used to study a specific product cycle, including its waste management, whereas in a 'solid waste LCI' all life cycle stages prior to the product becoming waste can be omitted if they are common to all the subsequent waste management options to evaluate. Hence product LCIs are of use to those who control product design and manufacture, while solid waste LCIs are useful for planners and managers of solid waste management systems. It should, however, be mentioned that the latter methods are not applicable if wanting information about how to reduce the amount of waste.

Purpose, functional unit and system boundaries

Many of the decisions that have the largest impact on the results are taken in the first step of a LCA and LCC - the goal and scope definition. Here, the purpose, the intended application and the reasons for carrying out the analysis must be clearly stated. Moreover, as a result of the purpose defined, the function(s) of the systems studied must be determined. This is done by clearly defining *functional unit*. As for LCA, the functional unit is defined in ISO 14041 which states:" In defining the scope of the LCA study, a clear statement on the specifications of the function of the product system shall be made. The functional unit defines the quantification of these identified functions – considered within the goal and scope of the study". It is not possible or feasible to cover every aspect of the life cycle of a product or service. Hence the *system boundaries*, the decision on what process units to include in the study, must also be defined in the goal and scope stage of a LCA/LCC. In comparative studies the functional unit and system borders should be equal, if not the differences must be clearly stated (Finnveden et al 2000)

If dealing with, for example, packaging in a life cycle perspective ("product LCI"), the functional unit could for instance be *Bottling, distribution and consumption of 1000 liter mineral water in Norway,* or it might be *Extraction, use and disposal of 1000 kg bottles applied for beverage purposes in Oslo region*. Both these functional units express a life cycle perspective. In the first functional unit, where the packaging works as a preserver of the beverage, the life cycle of the mineral water, including the bottle, is defined to be the product system, whereas in the latter example the bottles are selected as the product system. Both functional units are relevant and correct, it is a matter of what the scope of the study is defined to be.

The functional unit of a system that involves waste management of used packaging ("solid waste LCI") could vary. One example could be *production of 1000 kg secondary PET flake (RPET) from used bottles generated*. Another example of functional unit of a waste management study can be *treatment of 1000 kg used PET bottles into RPET and energy*. In the latter example, we can see that there are three functions; get rid of waste, production of secondary raw material, and production of energy and heat.

Normally when carrying out an LCA or LCC for a waste management system, the system borders include all flows from the waste source, e.g. from households (upstream-system border) to where the material is recovered into new products or energy (downstream-system border) (Finnveden 1999).

Open loop recycling and system extension
An important distinction in recycling is the one between open-loop recycling and closed loop recycling, see for example Graedel and Allenby (1995). In closed loop recycling disposed products are recycled into the same type of product, whereas open-loop recycling occurs if the used product is being recycled into a different type of product. Open-loop closing is the typically situation for used packaging and is for instance the case when used PET bottles are applied in the textile industry. In such a case the system boundaries between product 1 (the bottle) and product 2 (the textile) are not clear cut. According to Finnveden et al (2000) and Ekvall and Finnveden (2001) the problem can be solved in two ways, by allocation or by extension of system borders.

In the allocation procedure, which seems to be least appreciated among LCA and LCC experts, and where only one of the products is studied, three parts of the total system should be allocated between the two products: the recycling system, production of primary material used in both products (Lindfors et al 1995).

Although to date there are no absolute scientific agreements on how to deal with open loop recycling, many authors tend to think that system extension is the preferred method (Finnveden et al 2000). System extension is carried out to avoid the allocation problem. For instance, this is the case when comparing a waste management system that produces secondary raw material (A in Figure 3.5 below) with a waste management system involving incineration with heat production (B in Figure 3.5 below), both having the

same amount of waste as input. To be able to make an environmental- and/or economical comparison between the two systems they must have the same function. Hence, the borders of the system involving heat production should be extended with a function to produce alternative heat, while the recycling system producing raw material should also be extended to also include alternative raw material production, see Figure 3.5. If a waste management system produces both secondary raw material and heat, the system borders should be extended to include both alternative raw material production and alternative heat source. Alternative costs and emissions are deducted from the system's overall costs and emissions.
When extending the system boundaries in this way, impact from alternative raw material production, and/or alternative heat source, are usually withdrawn in the calculation of the defined system's overall impact (Finnveden et al 2000).

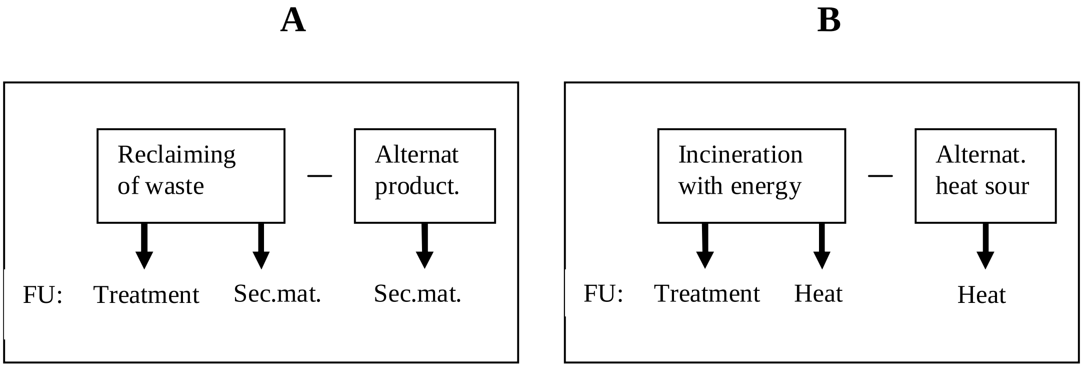

Figure 3.5: System extension of the waste management options of reclaiming into secondary raw material (A) and incineration with heat production (B) (modification of Finnveden 2000)

In the examples above it was assumed that secondary material produced from waste would replace alternative raw material and alternative heat. The replaced alternative could in addition to primary (virgin) raw material, also be secondary raw materials produced in other waste management systems, or a combination of both primary and secondary material. This is important since what you assume you replace when carrying out an LCA and/or LCC of recycling system will have decisive influence on the result, see for example Finnveden et al (2000), Lerche Raadal et al (2003), Bohne (2005), Werner (2000). There seems not to be any standardization in terms of what exact environmental and economical impact you replace when producing raw material and heat in waste management systems. However, it seems like it is most common to do as follows (see for example Lerche Raadal et al 2001):

- Avoided environmental impact of alternative production of raw material can be calculated on the basis of impact related to this production
- Avoided environmental impact of alternative heat source can be quantified by estimating the emission when using this fuel (e.g. emissions from oil combustion)

- Avoided economical impact, given as costs, can be found by identifying the purchase price (excl value added tax) of the alternative raw material and of the alternative fuel.

For several reasons it is difficult to make a sound decision on what is actually being substituted, what the alternative material or fuel is. The first and maybe most critical question is the extent to which secondary material and heat produced in a waste management system really will replace alternative production of raw material or alternative fuel, or whether it will simply come in addition to this production and hence give extra environmental and economical impact. In the global raw material market, and to a less extent energy market, it is almost impossible to follow the material and energy flows and check whether this is the case. If found that it will really replace, then another important question is what exact material or energy type, the secondary material and heat will replace. Another tricky question to be answered when applying system extension and corresponding assumptions of avoided emission and cost, is the extent to which secondary raw material produced in a waste management system has the same quality as the virgin material. If having equally good material quality it can be assumed that it replaces the actual (environmental) impact and emission from the alternative production. If the quality of the secondary raw material studied is somewhat lower, the material value is lower, and it may require higher environmental impact and cost to bring the quality to the level of the alternative material compared with. Werner and Richter (2000**)** suggest to correct for quality difference by subtracting only a share of the primary production avoided, as a ratio between the secondary to the primary production value per kg.

Before proceeding, I would just like to mention an interesting issue raised by Askham-Nyland et al (2003): They argue that reclaimed secondary raw materials are made available for use for several future life cycles and can therefore replace alternative virgin material more than just once. The authors, who apply a mathematical geometric progression approach, argue that this point should be included when analyzing recycling systems. This way of calculating costs and benefits of recycling will, however, not be applied in this thesis.

Multi-input allocation

Multi-input allocation problems are very common when studying recycling systems. These problems occur when several products are inputs to processes (Finnveden el al 2000), and it focuses on which emissions and costs/revenues should be allocated to which products. In the Norwegian deposit system, for instance, both cans and PET bottles are returned, transported and compacted in the same system. If only concerned about the eco-efficiency of the PET part of the system, the challenge is to find out how much of the environmental influence and economical performance that should be allocated to the cans and how much to allocate to the PET bottles. According to Finnveden el al (2000) the guiding principle should be to allocate on the basis of physical, chemical or biological sizes. In recycling system studies it is widely accepted to use mass as the allocation factor, see for example (Lerche Raadal et al 2003). For example, if a truck transports 10 tonnes of PET bottles and 10 tonnes of Al. cans, the two packaging types should be allocated

50 % of the cost and emissions each. Guinee et al (2004), on the other hand, argue that economic allocation is advised as baseline method for most allocations in a detailed LCA.

Data acquisition and level of detail

When a researcher carries out an LCA/LCC study access to data, often acquired from the most important decision maker in the system, it is of major importance. In many cases the decision makers in a waste management system may have good opportunities to give accurate data for the transport and processes they are managing or organizing. However, normally they will not have access to high quality data for all the waste management stages from used packaging to production of secondary material, see Figure 3.6 below. One reason for this could for example be that a re-processor is not willing to share information about costs and emissions data with externals. Besides, the level of detail of data should be higher “close” to the decision maker since these are the figures the decision maker have the largest opportunity to make impact upon. Rebitzer and Hunkeler (2003) illustrate this point very well, though not for a recycling system, when discussing the costs in light of various decision makers, see Figure 3.6 below. They are distinguishing between white boxes were detailed costs and revenues data are required or desired and black boxes where the requirements for data are less accurate and differentiated from the decision makers point of view.

If the perspective of the assessment is that of the user/consumer (see white box in bottom part of Figure 3.6), the costs within the boundaries of the other organizations/actors (black boxes) can be viewed as a black box, without requiring any differentiation between different cost types. On the other hand, if a manufacture is mainly concerned about, and has the possibility to influence, the detailed costs of producing the product, it may not need the various cost elements for consuming or recycling the product (see upper part of the figure).

According to Ehrenfeld (2003) an LCA/LCC may point to places along the product chain where impacts are highest and/or where improvements are most needed, but it cannot tell the decision-maker how to make them happen. In the next chapter we will see how the interactive resource development approach is able to grasp some of the dynamics in industrial networks.

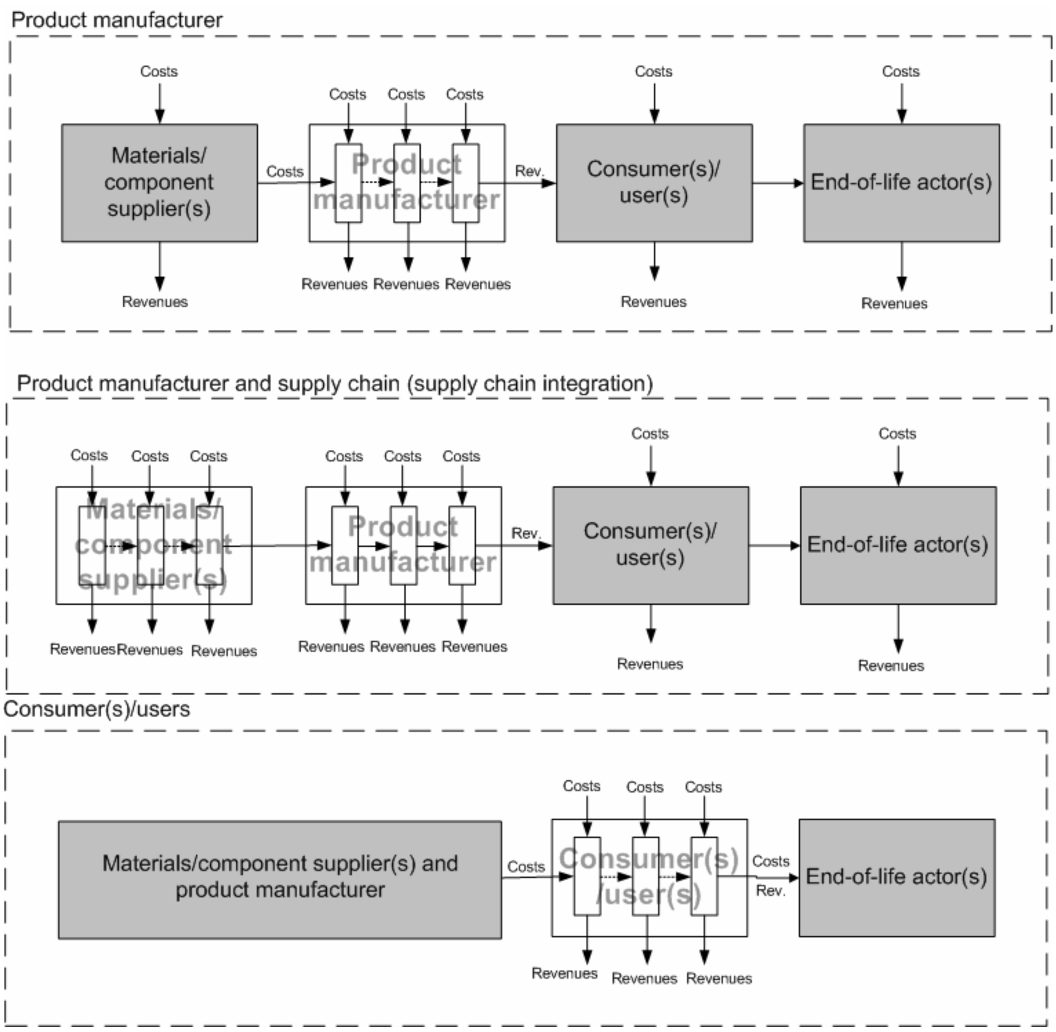

Figure 3.6: Different Perspectives in LCC (non-exhaustive examples)

3.4. Development perspective

3.4.1. Introduction

As we identified in section 3.1 Industrial ecology is also concerned about understanding development. This section mainly deals with interactive development of technology and other resources.

In the previous section we saw that the combination of eco-efficiency, LCA and LCC can be applied to quantify economic and environmental impact of waste management systems as well as other systems. However, this eco-efficiency approach cannot give any answer to why and how elements, and hence eco-efficiency, of a system change. In order to acquire better understanding of how for example bottles or beverage producers develop, another perspective must be included.

In Håkansson and Waluszevski (2002b), a brief presentation of some of the theoretical approaches to industrial development is given. Among the interesting arguments are:

- According to Bijker (1987) technology is *socially constructed* and develops through the *interaction* that takes place in a given network between actors and the conditions under which they interact.
- In contrast to technological management literature, where technological development is seen as an important tool for business to reach certain goals the companies can organize by themselves, Van de Ven et al (1999) sees technological development as often highly *unpredictable* and uncontrollable.
- However, even though we see changes all time, we also see that things are not changing even though it should. Because a resource element is *adapted* and related to some other resource element, it also restricts the resource element's ability to adapt to other elements. They are *locked in* existing structures and the flexibility of the system or structure decrease. Hence, change and development are restricted (Arthur 1988, David 1985, Dosi 1988, Hughes 1987, Bijker 1987).

Håkansson and Waluszewski (2002 b) have built their work on the abovementioned authors and claim that technological development is an interactive process which is neither stepwise nor something that takes place within the borders of companies. It is not a chronological process where knowledge creates innovation which thereafter results in new products or modified products that make changes in the industrial systems.

Before proceeding with Håkansson and Waluszewski, and others, on interactive development of technology and other resources, I will take a closer look at the industrial network approach, which is the foundation of the interactive development approach.

3.4.2. The origin of the industrial network approach

According to Dubois (1994) there is no single and totally accepted view of what a network is and how a network works, and it is therefore difficult to address to a particular model as *the* network approach. However, one important approach is the one referred to as the industrial network approach where, from a research point of view, an interactive perspective on industrial exchange is applied. This approach has, according to von Corswant (2003), its theoretical origins in social exchange theory (e.g. Emerson, 1962; Blau, 1964) and organization theory (Alchian &Demsetz, 1972; Thompson, 1967; Cyert & March, 1963). The origin of the industrial network theory is often dated back to the time Johansson (1966) discovered that long-term relationship was a very important factor in the international steel industry. The most important contributions during recent years have probably been the many papers and books published by the Industrial Management & Purchase (IMP) group[6].

Johansson (1966) found that through relationships a company's products, processes, and organizations are adapted and developed in relation to their counterpart's products, processes and organizations. They are *interactively changed* in dyads and networks. These findings are very much in contrast to classical economic model where it is assumed that a firm develops it's products, processes and organization in isolation while it provides the (invisible) market with service and goods the market asks for (Håkansson and Snehota 1995).

Networks consist of actors, activities and resources

Håkansson (1987) proposed a model that proved to become a valuable tool for description and analysis of complex industrial contexts, see Figure 3.7. This network model is based on three components; *actors*, *activities* and *resources*. Each of these components is seen as dependent on the other two. *Actors* are defined as those who perform activities and/or, directly or indirectly, control resources. In *activities* actors use certain resources to change other resources in various ways. *Resources* are means used by actors when they perform activities. Through these (circular) definitions a network of actors, a network of activities, and a network of resources are related to each other (Håkansson and Waluszevski 2002b).

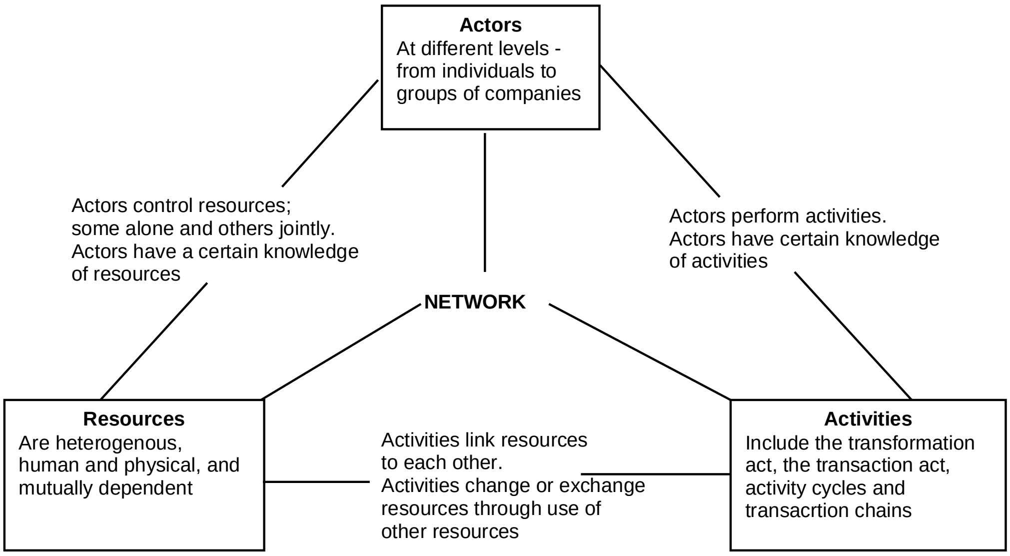

Figure 3.7: The Network model (Håkansson 1987)

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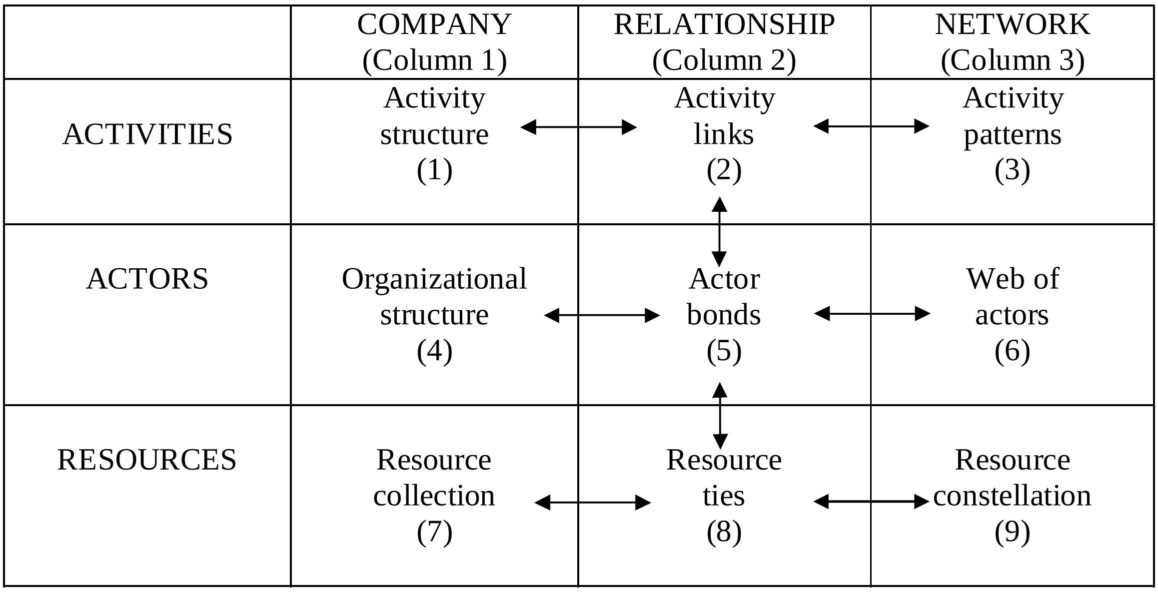
[6] The website www.impgroup.org gives a good insight

Importance of business relationships

In 1995 Håkansson and Snehota (1995) published a book on the importance of *relationships*, where they define relationship as a “mutually oriented interaction between two reciprocally committed parties”. A relationship has both structural characteristics and process characteristics. Important structural characteristics observed from empirical studies are continuity, complexity, informality and symmetry in resources and initiatives, while the process in a relationship is characterized by adaptation, co-operation and conflict, social interaction, and routines. Further, a relationship between two companies can be described by two dimensions, function and substance. In Figure 3.8 below the three different functions are shown:

1. A business relationship has effects on the *dyad itself* (column 2)
2. A business relationship has an effect on *each of the two companies* (column 1)
3. A business relationship has an effect *on other business relationship*, i.e. the whole network the business relationship is a part of (column 3)



	COMPANY (Column 1)	RELATIONSHIP (Column 2)	NETWORK (Column 3)
ACTIVITIES	Activity structure (1)	Activity links (2)	Activity patterns (3)
ACTORS	Organizational structure (4)	Actor bonds (5)	Web of actors (6)
RESOURCES	Resource collection (7)	Resource ties (8)	Resource constellation (9)

Figure 3.8: Scheme of analysis of development effects of business relationships

Three different layers of substance can be identified in a business relationship: *activity links*, *actor bonds* and *resource ties*. These can be regarded as three different effect parameters that are determinants of the values involved in a relationship.

1. A business relationship links activities. This layer is related to *productivity*
2. A business relationship ties resources. This layer is related to *innovation*
3. A relationship bonds actors. This layer is related to *identity*

An example of a business relationship in the Resirk system, which includes all three layers, could be one between a bottle supplier and a beverage producer. They will probably have a relationship connected to production of current bottles through an activity link, innovation of new bottle types through a resource tie, as well as an actor bonded supplier-customer identity based on for example how the bottles look like.

Interaction
Ford and Håkansson (2005) argue that structure and processes are important characteristics of the business world. The structure of the business world consists of relationships, whereas the processes within this structure are seen as interaction[7] between active and purposeful actors. This interaction is affected by and affects the relationships in which it occurs. One single actor can not decide how this interaction goes on or should go on, it is rather a process where the outcome is dependent on how an action is carried out by an actor is perceived and reacted by this actor's counterparts. These actions and reactions occur both in series and in parallel. In addition to affect on and be affected by the actors involved, interaction is also affected by and affects on the resources involved in the industrial network. Moreover, even though resources cannot interact in the same way as actors can, they influence and developed in relation to each other. They become adapted. This is referred to as interactive resource development, see 3.4.4 below. It is important to note, though, that resources do not have intentions and ability to act such as actors have, and therefore that the interactive resource development is initiated and maintained by actors.

3.4.3. The resource dimension

According to Gadde et al (2002) it can be argued that resources are the foundation of activities and are thus a very interesting factor to study. Resources are regarded as "facilitators of operations" in supply and distribution networks, including waste management systems. Beside, as mentioned above, while actors are connected to identity, and activity to efficiency, resources are connected to innovation and are hence closely connected to the change and development I am concerned about in this thesis.

In section 3.2 I have presented the framework for quantifying eco-efficiency of a life cycle system. Within the research programme NETLOG[8] at Norwegian School of Management (BI), one basic idea is that it is not sufficient to study actors, activities and resources in a supply, distribution or recycling system if the aim is to acquire information about change (Gadde et al 2002). The reason is that an actor (e.g. reclaimer), an activity (e.g. transport) and a resource (e.g. bottle) often belong to more than one system, and their participation and interdependencies with actors, activities and resources in other systems will influence their performance in the defined one. Influence from resources "outside" the defined system should thus be considered and analyzed in order to understand the development of resources and the performance in the defined life cycle system.

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[7] which is defined by Webster dictionary to be a "mutual or reciprocal action"

[8] The five-year programme began in 2001 and involves six full-time Ph.D students and senior researchers from the fields of logistics and industrial networks

Resources in industrial networks can be divided into four types: “Products” and “facilities” which represent the *technical/physical* dimension, and “business units” and “business relationship” which cover the *organizational* aspects (Gadde et al 2002). All four types of resources are highly interrelated and dependent on each other, see Figure 3.9 below. For example, in order to produce a product, we need a production facility that is owned by a business unit and in order to sell this product we need a business relationship. All these resource items and the relation between them must be included if the intention is to understand resource development in an industrial setting.

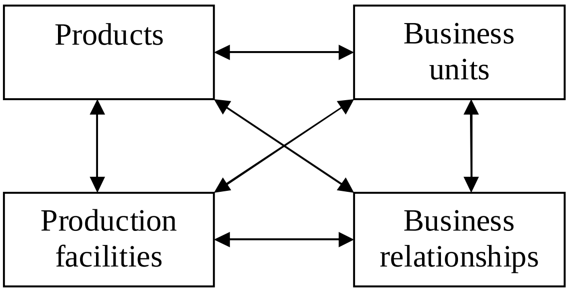

Figure 3.9: Four categories of resource items in a resource structure (Håkansson & Waluszewski 2002b)

Products

Products are parts of production systems and of user systems. They are exchanged between customer and supplier, and deal with the physical aspects of the flow of goods, service and information (Håkansson and Snehota 1995). Through interaction between supplier, customers, and users the unique feature of the product is shaped and created (Von Corswant 2003). Examples of products in the Resirk/PET system are beverages and secondary PET material.

Production facilities

A facility is a resource that transforms products into other products, is interactively developed and is often of a physical nature. Facilities can for example be buildings, vehicles, equipment, machines, railways etc, and are used as means for creating time, place and form utility by directing the flow of goods, service and information (Håkansson and Snehota 1995). According to Gadde et al (2002) we can distinguish between fixed facilities (such as warehouses and carrier terminals) and transportation facilities, which connect the fixed facilities. Due to, usually heavy, capital investments, facilities are often seen as heavy resources (see section 3.3.4) which may create so-called lock-in effects (Von Corswant 2003). RVMs, the PET spec, and filling machines are among many production facilities in the Resirk/PET system.

Business units

According to Gadde et al (2002) a business unit is both a problem-solving actor and a resource which can be used by others. The business unit resource is a reservoir or a set of knowledge, capabilities, experience, routines and traditions, all developed through interaction with business units and other resource items. In addition, the business unit is the basis for the settlement of economic deals, balance sheets, profit and loss accounts (Håkansson and Snehota 1995, Von Corswant 2003). The business unit, which can be a firm, an organization or a part of a firm or organization, has the motivation and ability to co-operate. This ability and motivation is an important condition for interaction to occur. In the Resirk/PET system, we have business units such as consumers, producers, importers, and Norsk Resirk.

Business relationships

A business relationship is established when resource elements in one business unit are connected to resource elements in another business unit. The two-folded content of a business relationship should be emphasized: Business units are connected through relationships that couple them together through actor bonds, activity links and resource ties (see section 3.1), and at the same time business relationships are important resources for the business units involved (Håkansson & Snehota 1995).

A business relationship represents strategic resources in three ways (Gadde and Håkansson 2001):

- in itself (a few relationships account for the vast majority of sales income, procurement etc)
- direct relationships connects a focal company to the rest of the network
- connects physical and organizational resources with its counterpart (e.g. adaptation of technologies across firm boundaries).

A business relationship must be developed in breadth and depth to utilize resources in another company in the best way. It requires investments and may be costly to handle. It may also give rise to lock-in effects (Håkansson and Waluszewski 2002 b). If we again use the Resirk/PET system as an example, business relationships can for example be found between consumers and beverage producers, and between beverage producers and Norsk Resirk

3.4.4. Interactive resource development

Technological development

Technological elements, such as bottles, RVMs, filling plants in the Resirk system, develop and change all the time. Examples could be new types of bottles enter the system, that new sorting technology for separating bottles appears, or specifications deciding how the bottles or the RVM should look like change. But how can we understand this technological development?

According to Håkansson and Waluszewski (2002 b) there are at least three features of technological development:

- There is no linear connection between intentions and outcome
- There exists no "true" picture of certain development process. It is rather an interpretation of problems and opportunities dependent of the beholder
- Technological items are both objects and economic means

The first feature means that instead of treating technological development as a linear chronological process, Håkansson and Waluszewski (2002 b) see such development as something that happens between several companies through interaction, and where the outcome is uncertain and often something else than the company that initiated the process planned. In the Resirk/PET system the suppliers of reverse vending machine had an idea of how the reverse vending machines should function before the development process started. However, as this machine had to match with other actors' interests as well as other technological components in the Resirk/PET system, and since these influenced the development process, the final outcome of the machine was probably different compared to the supplier's original plan. Technical items are developed and adapted in relation to each other. Hence, technological development is an interaction process where a company's established resources and structure, as well as its ideas on how to develop, are constantly confronted with the structures, ambitions and technologies of other companies. Such an interaction is neither like a jungle nor like a rain forest, it is both in the sense that interaction contains both conflict and co-operation (Håkansson and Waluszewski 2002b).

Secondly, for example in the development process of the RVM, there is no true picture of how the machines really developed. People employed at the RVM supplier will tell their story on how the machine evolved, whereas for example the beverage producer, which has to make sure that the bottles to be returned by the consumer fit into the reverse vending machines, will have another perception of the development process.

A third feature of technological development is that technological items can both be objects as well as economic means. If we again have a look at the RVM, it is obvious that the suppliers see the machines as an economic means, whereas for example the consumers see them as objects that receive used PET bottles.

Resources are heterogeneous

During the last five years, several studies within the industrial network approach have been occupied with interactive resource development, particularly technological development, which we had a quick look at above (see e.g. Wedin 2001, Håkansson & Waluszewski 2002b, Håkansson & Waluszewski 2002a, Dubois and Torvatn 2002, Holmen and Pedersen 2002, von Corswant 2003). In classic microeconomic analysis the basic assumption is that the value of a specific resource is given – i.e. the value is independent of how this resource is combined with other resources. Resources are regarded as homogeneous, and the key issue is to allocate these given resources to given means (Pasinetti 1981). The opposite view, and the view the industrial network approach is based on, is the assumption that resources are heterogeneous – i.e. the value of a resource can and will vary, depending on how it is used and particularly on the ways in which it is combined with other resource elements (Alchian & Demsetz 1972). The heterogeneous resources are *interactively* used and developed (Håkansson & Waluszewski 2002b). An example of the relative value of a heterogeneous resource: Twenty years ago packaging waste was perceived as (useless) waste. Today (business) people to an increasing degree see waste as a raw material to be used for new production. The waste is the same as before, but today it is combined in another way than before and hence has a value.

Resource adaptation

According to Gadde et al (2002) resource development is not mainly about great new innovations: "to a large extent resource development is all about using existing (heterogeneous) resources in novel ways, for example by exploiting unused features of the individual resource elements and/or combing the elements in new ways". Hence a product, will, through adaptation and combination with other products, production facilities, business units and business relationship appear, develop and eventually disappear. The outcome of an interactive development process, which is often more a change of existing solutions rather than new spectacular innovation, is not given and hence it is difficult to predict or fully manage the process of change (Håkansson & Waluszewski 2002b). Nothing developed through interaction is given since the interaction process is created and re-created again and again (Håkansson & Waluszewski 2002b). However, the more comprehensive and long-lasting the interactions between actors are the more adapted will the resource items be. According to Arthur (1986) technology resources become more attractive the more developed, widespread and useful they are, i.e. the more they are adapted. Figure 3.10 below illustrates how resources can become more and more adapted as time go by. Through interaction between actors resources influence each other, and this results in changes in one or several of the resource elements involved. They change in such a way that they become more adapted. A good example of this could be the RVM machine in the Resirk system, which has been modified several times since it was introduced in Resirk and other markets in 1999. This development is a result of adaptation with interrelated resources such as bottles and Norsk Resirk.

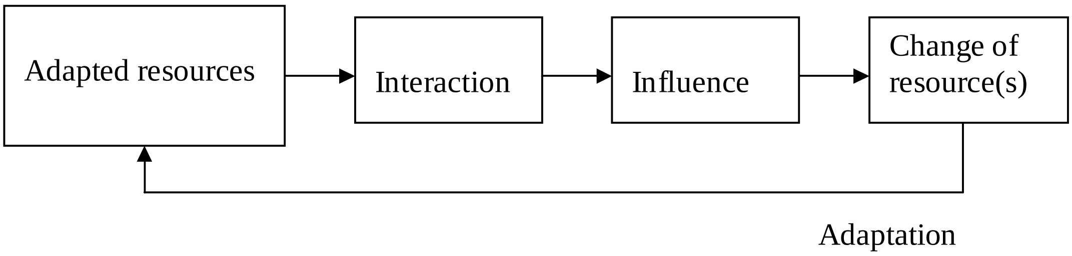

Figure 3.10: The adaptation of resources

Håkansson & Waluszewski (2002b) have found the following four interaction processes to be particularly important to development of the various categories of resources:

- Buying/selling is important for the development of products
- Producing/using have impacts on facilities
- Co-operating processes connect and influence on business units
- Networking processes relate and develop business relationships

Focal resource and resource interfaces

Interaction creates and develops not only resources but also *resource interfaces*[9] between various resource items (Håkansson & Waluszewski 2002b). These interfaces relate the content in separate resources. Every interface is unique and contributes to give the resources their unique features. A framework for analysing how resources and resource features are interactively used and developed, how they influence each other, as well as how they are currently embedded into each other, is illustrated in a network triad[10] in Figure 3.11. Or as Wedin (2001) put it: ".. the interfaces between different resources are important factors if one is to understand what conditions govern the use of a focal resource, and also to determine under what conditions the value of this resource is created and realized". According to Forbord (2003) an interface is something that *is* between resource elements, whereas interaction is something that *happens* between resources.

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[9] Instead of resource interface Von Corwant (2003) uses the term dependency which can be analyzed in terms of ties between different resources.

[10] A triad is selected for simplifying and illustrating reasons. Often more resource elements will have influence on the focal resource.

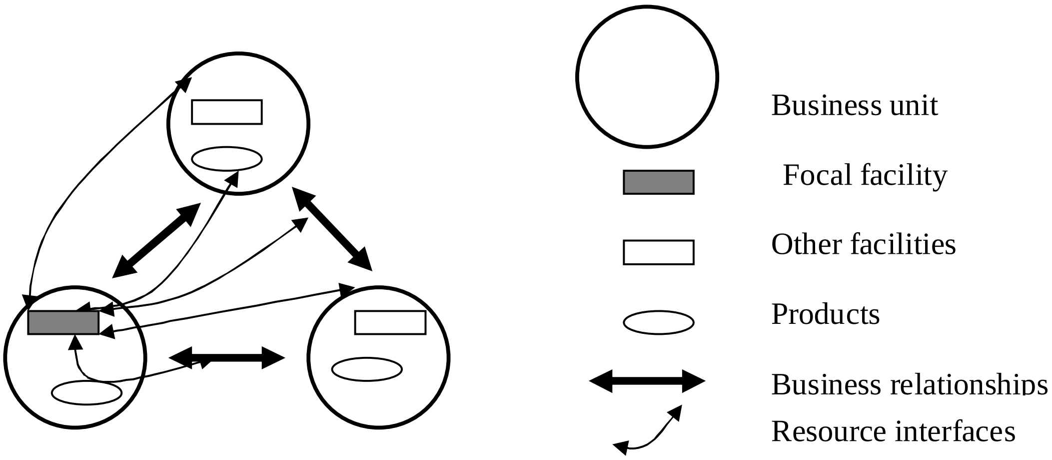

Figure 3.11: A framework to analyze resources and embeddedness in a resource network triad (Wedin 2001)

In order to study resources in a network it is necessary to define a starting point, a focal resource (in Figure 3.11 above chosen to be a facility). The resource interfaces (illustrated by thin arrows) between the focal resource and the other resources are created and developed as a result of interaction between the resource elements. Thus, the components, characteristics and features of the focal resource and related resources are developed. The characteristic “quality” of a product such as for example PET bales made in a waste management system, will be developed through interaction and establishment of resource interfaces with resource items such as the reclaiming plant that re-process the PET bales. A resource interface can only be identified in those cases where one or both of the two resources have been developed in relation to or have a clear impact on each other. Hence, it is likely that there is a resource interface between the bottles and the RVM, whereas there might not be an interface between the bottle and the production plant, which uses PET flake as secondary raw material. It should further be mentioned that in order to acquire a sufficient level of detail, demarcation of what and delimitation of how many, resources and resource interfaces to include in the study is required (Forbord 2003)

In the Norwegian research program NETLOG a framework for analysis of a focal resource and its interfaces with related resources is developed (Gadde et al 2002). In this framework, important resource interfaces, in terms of degree of connections, adaptation, marking, time and space, share of values and costs between resources are identified and analyzed.

Embeddedness

As we know from daily life, many resources change and develop all the time, however, at the same time, we also know that it is sometimes difficult to change or develop a product or an organization. So under what conditions can resources be developed, and in what situations does it seem difficult to change them? First of all we know that development must always begin with the existing structures (Håkansson and Waluszewski 2002a).

This point is very well demonstrated in a paper by Torvatn et al (2000). They have carried out analyses of three different companies who acquired a new resource, but where it differed in terms of how these new resources were able to be adapted into the existing resource structure. A better analysis of existing resource structure before investing in new resources could have improved the outcome of the resource development, they argue. In addition to illustrate resource interfaces between resource items, figure 3.11 above also illustrates how resources and resource interfaces are *embedded* in an existing resource structure. Certain features of single or combined resource items are developed and embedded into each other through interaction (Håkansson and Waluszewski 2002b). The resources become embedded when they are adapted and combined with other resources in a larger resource structure (see e.g. Hallinen & Törnroos 1998; Ford et al. 1998). From a network perspective this resource embeddedness stretches far across firm boundaries, and therefore no firm can decide on development and adaptation in isolation (Von Corswant 2003). Von Corswant (2003) states further that technological embeddedness cannot be viewed isolated from other types of embeddedness since, for instance, social, economical and technical embeddedness are interrelated. Product development will for example have impact on social structure as well as economic performance and vice versa. Hence, it gives more sense to speak about an "overall" embeddedness, rather then about technological embeddedness and other types of embeddednes.

The embeddedness has consequences for how the resource can be used in new combinations with other resources. Often it is seen solely as a hindrance towards change or development. Rosenberg (1994), for instance, argues that as a resource becomes increasingly embedded in the resource structure, it may also be more difficult to change it. However, according to several authors (Von Corswant 2003, Håkansson and Waluszewski 2002a, Håkansson and Waluszewski 2002b, Uzzi 1997) embeddedness gives *both* limits and possibilities for change. "Embeddedness is required for (efficiently) utilizing and economizing on resources but, at the same time, it limits the possibilities of change" (Von Corswant 2003). In the Resirk/PET system, for example, it is likely that the interfaces between the RVM and the bottles, due to adaptation and embeddedness, hinder technology development of both the bottle and the RVM in other directions. However, due to the fact that they are embedded, and hence have the opportunity to meet, it is ensured that they will develop interactively.

Heaviness and variety

One way to characterize embeddedness in a resource structure is to look at the features of *heaviness* and *variety* of the resources involved. Heaviness can be seen as an obstacle towards change of resources in resource structures, while the variety expresses the ever-present possibility to change resources.

Heaviness of resources is expressed in all those investments in items which are interactively developed in relation to each other (Håkansson and Waluszewski 2002a). This may be capital investment such as a bottling plant or intangible investments such as knowledge or trust. Håkansson and Waluszewski 2002b distinguish between *economic* and *functional heaviness* of technical resources. The economic heaviness is expressed by the extensive technical, social and economic effort that is behind the development of new technical solutions (Hughes 1987, Bijker 1987), while the functional or directed heaviness is shown as how, or in what direction, the resource is connected and developed in relation to other resources. Functional heaviness is strongly related to what benefit a resource can create in relation to and through other resources (Håkansson and Waluszewski 2002a). Resources have a mass of technical and organizational components, they posses direction, or goals, and they display a rate of growth suggesting velocity (Hughes 1987). Hence, due to economies of scale, learning and interrelatedness resources are "locked in" over time, but only for some in some directions (functions). In other directions the resources are not locked in and can be moved when new crossroads of old paths are created. This phenomenon is well demonstrated in a case study of the innovation of IKEA's "green" catalogue paper (Håkansson and Waluszewski 2002a). The authors have shown that the development of this new type of paper was dependent, not restricted, to earlier investments and experiences in certain resources, such as production facilities and supplying units. These resources already belonged to other paths and were parts of other resource collections before the development of green paper started. However, when these paths met, development of the green catalogue paper was established. From this we have learnt, according to (Håkansson and Waluszewski 2002a) that in some situations *path dependence* will be a stimulation of change, not solely a hindrance as many argue (Arthur 1988, David 1985, Dosi 1988).

The variety of resources is one important reason for this stimulation of change. Because within the heavy resource structures, there is a great variety, both in terms of existing methods of combining and activating resources, as well as in development possibilities (Håkansson and Waluszewski 2002b). As mentioned before, resources are heterogeneous, and hence there is always the possibility to change or modify them. A product can be combined with other products or other facilities and these new combinations can give new features of the products.

From a network perspective all resources are characterized by a certain degree of both heaviness and variety, and they can through interaction both create drivers and hindrance in resource interfaces (Håkansson and Waluszewski 2002b). Variety and heaviness interfere in the process of creating new solutions or trying to protect old solutions. The embeddedness, characterized by heaviness and variety in a resource structure, is a result of previous (and current) interactions, and at the same time it has consequences for future interaction and resource development. So if the aim is to explore possible future changes, then the heaviness and variety of current resources and the appurtenant hindrance and drivers in the interfaces connecting them, should be studied.

Friction

Friction can illustrate how embeddedness affects the possibilities to change resource structure (Håkansson and Waluszewski 2002b, Von Corswant 2003). The friction has both a stabilizing and destabilizing effect, see figure 3.12. Friction is a stabilizing force that makes it difficult to move (heavy) resources in relation to each other due to their interaction and embeddedness. However, friction also implies that the changing force applied to an embedded (focal) resource will be distributed to other elements in the resource structure. Interrelated resources and features of resources may then break up and new (unknown) features and combinations will appear. In this way the friction has a destabilizing effect. The stabilizing- and destabilizing effects of friction are closely connected to heaviness and variety. Heaviness may increase the stabilizing effect, while variety refers to difficulties to predict the destabilizing effect of friction between more or less embedded resources.

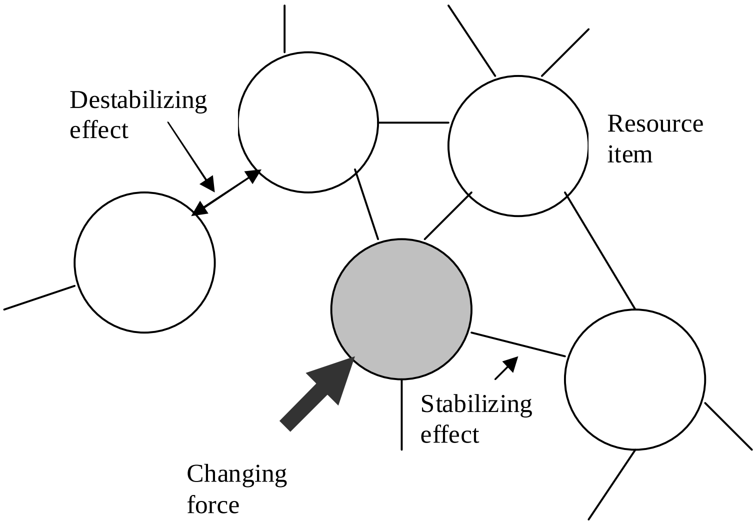

Figure 3.12: Friction, a result of a changing force, has a stabilizing effect on some resource interfaces and a destabilizing effect on others (Von Corswant 2003)

The phenomena of friction can be explained by looking at a changing force that hits a (focal) resource that is connected to other resources, see Figure 3.12 above. According to Corsvant (2003) the changing force will through friction, a force which only appears between related surfaces and only as a reaction to another force, produce a reaction that will:

- be <u>distributed</u> to resources that have both direct (near) and indirect (distant) interfaces with the focal resource
- create <u>tensions in the interfaces</u> between these resources which in turn can change some resources in relation to each other – and sometimes even create new resources
- have different effects over time, given the way the resources already move in relation to each other – that is, the effect is <u>time dependent</u>.

An interface between two well adapted resource elements can be characterized as a stable or strong interface, while an interface between two resource elements which are not well adapted can be characterized as an unstable or weak interface (Von Corsvant 2003). Both resources connected through stable or through de-stable interface can change as time pass by, even though it is more likely to find changes if resources connected to a weak interface are exposed to changing- or other forces. On the other hand, the changes may be larger if resources connected through a strong interface are influenced.

As illustrated in the figure above resources are directly or indirectly connected to the focal resource, and could hence have directly or indirectly (via another resource) influence on the development of the focal resource (Jahre and Fabbe-Costes 2003). Vice versa, due to interaction between the actors involved, the focal resource may also influence on the development of these directly and indirectly connected resources.

Systems vs. networks

Before leaving the issue of interactive resource development, I would like to take a brief look at the differences between the life cycle system perspective, which is used in the eco-efficiency analysis, and the network perspective, which is the foundation for analysis of interactive resource development. As mentioned before the basic idea is it's not sufficient to only study the actors, activities and resources within a defined supply-, distribution- or recycling system if the aim is to acquire information about changes since also elements beyond the defined system boundary contribute to changes. (Gadde et al 2002). Another important difference between life cycle system analysis and analysis of industrial network hence the degree of rigidity.
In life cycle analyses clear system boundaries and system, function are defined, while there seems not to be the same degree of pre-determined fixed starting point when analyzing networks of actors, activities and resources. 'A network has no clear boundaries, nor any centre or apex' (Håkansson and Snehota 1995, p.40). Or, according to Dubois and Torvatn (2002), "…any boundary can be drawn in a network. No boundary is inherently better or worse than any other is. However, certain boundaries present us with a useful way of analyzing certain phenomena" Or as Gadde and Håkansson (2001, p.181) put it: 'From an analytical point of view it would be possible to find an optimal solution provided we could define a clear-cut network with one specific boundary. But network boundaries are always arbitrary – they are based on perceptions and are continuously changed' Further they argue that it is '…. impossible to come up with a 'master network strategy' taking every aspect into consideration….strategies are always partial and they are valid only for the time being, and must continuously be changed and altered (p.183). The main idea is that there no fixed network that should be analyzed or optimized in a particular way.

In this chapter I have presented what I think are some of the most important perspectives within the field of industrial ecology. The two first perspectives, the system and life cycle perspective and the environmental-economic perspective, will be applied to answer research question 1 and 2. By using these two perspectives I hope to be able to answer how the eco-efficiency of the Resirk/PET system has changed during recent years, and which parameters have influenced on the measured eco-efficiency. Research question 3, on what factors that shape the parameters influencing on the eco-efficiency, will be answered by help of the interactive development perspective, what I suggest to be a third important perspective within industrial ecology. Hence, research question 1 and 2 refer to a quantitative eco-efficiency analysis of "how" eco-efficiency has changed, while research question 3 refers to a qualitative interactive resource development analysis of “why” the eco-efficiency has changed. By combining these two approaches I hope to acquire a better understanding of the Resirk/PET system than use of only a qualitative or a quantitative approach would have given. Moreover, provided I succeed, such a combination could hopefully give a contribution to the field of industrial ecology (research question 4) where questions on “how” and “why” industrial systems change are central.

4. Methodology and methods

Methodology is, according to Vafidis (2002) a philosophical issue concerned with the worldview and starting point of the scientific investigation, whereas methods are about what technological approaches and tools that are used for making empirical observations. Research methods refer to the methods and procedures that are used to gather and analyze data related to research questions or hypotheses. However, it is important to note that methodological approach and method are connected because the methodological basis will have an influence on research questions defined and on which methods are used to answer these questions. This chapter deals with methodology and methods. In section 4.1 I will clarify my methodological approach to this thesis. Thereafter, in 4.2 and 4.3, definitions, delimitations and assumptions made when applying the research methods of eco-efficiency analysis and interactive resource development, respectively, are presented. In 4.4 I will present the methods I have applied to gather data for the eco-efficiency analysis and for the interactive resource development analysis.

4.1. Methodological approach

According to Vafidis (2002) the methodological choices of research depend fundamentally on the ontological and epistemological beliefs of the researcher. Ontology refers to existence, i.e. the assumptions of the claims of what exists and what that exists looks like. Epistemology refers to in which it is possible to gain knowledge about the reality. Hence ontological beliefs determine the assumptions which a researcher has about the research object, while epistemological questions determine the possible ways to gain knowledge about the research object. In the case of the Resirk/PET system one could say that my ontological belief is that there exists a recycling system with elements such as material flows, trucks and RVMs, and which has an environmental and economic performance, whereas the epistemological questions refer to how I can acquire information about the environmental and economic performance of the Resirk/PET system.

Vafidis (2002) has conducted a study to reveal the methodological approach of 25 Nordic dissertations within logistics. In order to do this he proposed a framework consisting of ten dimensions to analyze the methodological approach the researchers have had:

1. Level of research problem
2. Level of empirical evidence
3. Named qualitative method
4. Named quantitative method
5. Openness of framework
6. Contribution to theory testing
7. Contribution to theory generation
8. Pragmatism

9. Main theory applied
10. Research approach order

In order to explain and justify my methodological approach in this thesis, I will try to relate each of these ten dimensions to what I am doing.

Level of research problem

The level of research problem refers to the aim of the research, related to which level of the economy that is represented (Vafidis 2002). In an eco-efficiency context we could say that the micro level relates to a company or a single product, the meso level refers to a whole sector or business type, whereas the macro level refers to issues within the national or global economy. I have selected to study a national recycling system, and hence we may call it a macro approach. However, only looking at relatively minor goods as PET bottles, I would argue that my defined research problem should be placed at the meso level.

Level of empirical evidence

According to Vafidis (2002) the level of empirical evidence relates to the level of the data the researcher has had access to. Macro level data is publicly available, while micro and nano level data require tighter collaboration with specific companies and individuals. In my study of the Resirk/PET system, I have had good access to system and company specific data (see chapter 4.2 - 4.4) and I think it would be fair to place my level of empirical evidence within the micro category.

Named quantitative and qualitative methods

The research methods selected should reflect the purpose of the thesis (Vafidis 2002). My purpose is to analyse the Resirk/PET system from an eco-efficiency as well as development perspective. This will be done by applying both quantitative as well as qualitative methods.

The methods selected refer to the way data are gathered and analyzed. According to Encyclopedica (2005) quantitative methods are research methods concerned with numbers and anything that is quantifiable. They are therefore to be distinguished from qualitative methods. Counting and measuring are common forms of quantitative methods. The result of the research is a number, or a series of numbers. These are often presented in tables, graphs or other forms of statistics. The qualitative method is a research method that deliberatively gives up on quantity in order to reach a depth in analysis of the object studied. It uses different techniques doing so. Qualitative interviews, focus groups, content analysis, participant observation and participation are some of the most important. Qualitative methods are commonly used in conjunction with quantitative methods. However, they are often used in combination to acquire a better understanding of the phenomena studied; for example by using qualitative methods it is often possible to understand the *meaning* of the numbers produced by quantitative methods.

I am studying the Resirk/PET system and hence I am having a single-case study approach. A single-case study focuses on a single case only, while a multi-case study include two or more cases within the same study (Yin 1993).

Case study is often referred to as a qualitative research method. However, as Yin (1993), Ellram (1996) and Stock (2003) point out quantitative approaches can also be employed in case research. It is also arguable whether case study is a single method. From my experience with the Resirk/PET case I would agree with Vafidis (2002) who states that the case study is no single method but that various methods, quantitative and/or qualitative, are used to fulfill the purpose of the research study. In my thesis this is very much the case since I am using the method of eco-efficiency to quantify as well as the qualitative method of the interactive resource development to understand more about "meaning of the numbers produced". Data gathering by Internet and literature search as well as qualitative research interviews can be characterized as qualitative methods.

Another way to categorise the case study approach is to see whether it is used for exploratory, explanatory or descriptive purposes. In exploratory research, the issue could be how or why is something being done. A case study can provide more depth and insight into a little known phenomenon (Ellram 1996). In explanatory case study research the aim is to explain the cause-effect relationships, while a descriptive case study is conducted to describe a phenomenon within its context. My case study is mainly of a descriptive and explanatory character. It is descriptive in the sense that the aim is to describe how the system and resource elements are connected, and how efficient the system is. The explanatory element is included since I am concerned about what parameters and factors that contributes to the system's eco-efficiency.

Openness of framework

The question of openness of framework relates to what extent the framework is predefined before collection of empirical evidence and is not open for change even though the empirical findings are in contrast to what the theoretical framework would have accepted. According to Vafidis (2002) the researcher should choose an open framework which allows for changing, if the purpose of the research is to generate new theory (the hermeneutic tradition), whereas a more fixed framework should be applied if the purpose is to test the validity of a framework, what is called the positivistic hypothetic tradition. In my research I would say that I am doing both. Before collecting empirical data I started off with a life cycle-oriented eco-efficiency approach. This framework was only slightly modified during the research period. However, after applying this approach for a while I found that it was not possible to understand "the meaning of the numbers produced" and therefore I introduced the interactive resource development approach, which remained unchanged throughout the period of collection and analysis of empirical data.

Contribution to theory generation

According to Bothamley (1993) a theory is "a general principle supported by a substantial body of scientific evidence which explains observed facts". A theory can explain, understand, predict and manipulate phenomena (Vafidis 2002). Theory seeks to find the answer to the question of "why" (Vafidis 2002)

Research is often separated into theory developing (inductive) and theory testing (deductive) (Vafidis 2002). Again I would say that my research is characterized by both these types of research, even though it should be mentioned that my aim to a large degree has been to gain knowledge about the Resirk/PET system in order to be able to answer research question 1, 2, and 3, see Chapter 1.4. However, as a consequence of this case study research, I have made theoretical contribution on how two different approaches, the quantitative eco-efficiency approach and the qualitative interactive approach, could be combined in a systematic research methodology. This work, which was related to research question 4, may qualify as theoretical contribution to industrial ecology. Some new theoretical findings may also have been added to the interactive resource development approach. At the same time I have had a theory testing approach since I had to modify the eco-efficiency framework to be able to answer the research questions proposed.

As mentioned above I have a single case study approach. It should be mentioned that there are heavy discussions in the scientific world to what extent such an approach can contribute to theory generation. Eisenhardt (1989) argues that at least four cases should be analysed to produce new theory. Repeated observations of the same objects must be done in order to qualify for theory building, she argues. Due to the scarcity of observations, the one case study approach can neither be used to reject nor support a theory. However, Dyer and Wilkins (1991) argue that single-case study approach allows for conducting an in-depth study of a phenomenon and hence give better opportunities to understand the deep structures of a single case. Theory that is born in such deep insights will be both more accurate and more appropriately tentative because the researcher will take into account the particular context the phenomenon is studied, Dyer and Wilkins (1991) argue.

Pragmatism

The two main traditions of science are positivism and the hermeneutic tradition. The positivistic tradition is characterized by an emphasis on empirical data, which is analyzed to verify or falsify the theory suggested by the researcher before she started to collect data. In order to be objective, and not include her value or preferences, the researcher must be kept independent of the research object, the positivists argue. Positivist research seeks to find law-like relationship and generic knowledge through causal explanation (Giddens 1994). In the hermeneutic tradition the aim is not to make objective explanations but rather to understand the phenomena through interpretation (Vafidis 2002).

Positivist and hermeneutic researchers are concerned about testing and building of theory, respectively. In pragmatism the truth of the theory is not considered relevant as long as the theories work well in practice. Theories are considered as instruments to gain experience, and the goodness of the theory depends on whether it works in practice. The pragmatism emphasizes the need for the researcher to tailor or modify theories to make them applicable to the problem to be solved. I would argue that I have a relatively pragmatic approach to my research. The aim is to produce knowledge about a given system and theories and methods are modified applied for this purpose. However, and partly as a consequence of this, theoretical contribution to the field of industrial ecology has also been central. It should be mentioned, though, that the aim of my thesis is not so pragmatic that it aims to provide the decision maker of the Resirk system instruments or results to be used in daily operations.

Main theory applied

I have not applied one main theory in my case study research. In tradition with the industrial ecology approach I have applied a mix of several theories and approaches; system theory, life cycle system theory, eco-efficiency theory, and network theory, see chapter 3 for descriptions

Research approach order

Vafidis' (2002) final dimension to identify methodological approach of research refers to which order the theories (T), methods (M) and observations (O) of my research have been carried out. The positivist researcher will first decide on theory and (thereafter) method and then find an arena for empirical observations to test the theory and/or method. In the inductive traditions the observations will come first in order to build a theory.

I would characterize my research as more iterative than just purely inductive or deductive. I started with a theoretical framework (the concept of eco-efficiency) and proposed a method (life cycle based eco-efficiency analysis) which was used to analyze the empirical data. In this way it seems I followed the positivistic T-M-O route. However, throughout the research period I had to slightly modify the theory and method before again going for more empirical evidence. Moreover, the empirical observations made me interested in bringing in a new theoretical framework, the interactive resource development, which I thereafter applied to analyse a new type of empirical evidences. However, neither the interactive development analysis was straightforward; I needed to change focal resource three times before I was able to find a starting point which was sufficiently connected to the important findings of the relevance of volume and return rate in the eco-efficiency study. Hence, due to the iterative nature of my research, I would argue that it is not meaningful to place my use of theories, methods and observations in a particular order.

4.2 Eco-efficiency: Delimitations and assumptions

In this section I will present the delimitations and assumptions I have made in order to do the eco-efficiency analysis in chapter 5.1.

4.2.1 Norsk Resirk's mandate and perspective

An eco-efficiency analysis, included the indicators applied, could be based on the perspective of the decision maker, who is going to apply the results from the analysis, or the researcher who is conducting the analysis to answer her research question. In my case study of the PET bottles in the Resirk system, I have chosen to combine these two approaches. Norsk Resirk, the main decision maker in the Resirk system, has been given a mandate by the Norwegian Ministry of Environment, which is translated into a mission to "establish and operate a non-profit deposit and recycling system for one-way beverage and soft drink containers which (Norsk Resirk 2002):

- Has high objective in recycling, 90-95% long term
- Is environmental, competition-neutral and cost-efficient.

This is the perspective of Norsk Resirk's work. My research contribution, which is built on Norsk Resirk's perspective, is to answer the research question of to what extent the economical and environmental efficiency in the Resirk system for PET bottles has changed during recent years and, moreover, to find what the important parameters to this efficiency has been.

4.2.2 Selection of eco-efficiency indicators

As presented in Section 3.3.1, eco-efficiency of a recycling system or a waste management system can be expressed by the following equation:

$$Eco\text{-}efficiency \equiv \frac{Environmental\ influence}{Cost}$$

This is a general equation, and the next challenge is therefore to find indicators that can express environmental influence and cost of the Resirk system.

In contrast to its prescription of describing *all* relevant aspects, the WBCSD claims that eco-efficiency analysis should be aware of producing too excessive information (WBCSD 2000). As we will see below, I suggest to use only one indicator to calculate environmental influence and one indicator to quantify cost. In the following I will explain why *net cost* may be a sufficient indicator to express cost of the Resirk/PET system, and why *net greenhouse gas (GHG) emissions* seem to give a good indication of environmental influence.

Net cost as cost indicator
Management of waste management systems is usually a matter of reducing the costs of recycling and other waste management options included at the same time as high recycling rates are acquired. We have seen that Norsk Resirk's mission is to organise cost-effective recycling. The incentive for producers and importers of beverages to be a part of the Resirk system is to see the packaging tax of the beverages they sell to the market reduced. The tax level is connected to the national average recycling rate of the PET bottles in the Resirk/PET system, see chapter 2.2. However, this tax reduction is partly outweighed by the administration fee the producers and importers have to pay for each bottle they introduce in the deposit system. Hence, in order to achieve a non-profit situation, Norsk Resirk must make sure that the incoming administration fee (along with unclaimed deposit) covers running and administration costs. So, in general increased costs give increased administration fee. Moreover, producers and importers are jointly, with the retailers, owners of Norsk Resirk. This means that there are several incentives for making the cost of the system as low as possible. From this angle it seems reasonable to apply cost as economical performance indicator to quantify eco-efficiency of PET bottles in the Resirk/PET system. The next question is how cost should be quantified.

The cost of waste management is a very widely analysed and debated issue within the scientific community, see for example Bruvoll (1998), GUA (1999), Eggels el al (2000). As mentioned in chapter 3 Bohne (2005), Huismann (2003), Salling et al (2002) have found ways of expressing cost of waste management systems. Wollny and Schmied (2000) mention cost-benefit analysis and prevention costs as possible approaches for estimating costs in recycling systems. APME (2000) and Jenseit et al (2003), use an eco-efficiency model developed by BASF to calculate the cost balance. Credits achieved through substituting virgin material with recycled material are included in this cost balance. The cost methodology in Weitz et al (1999) calculates annual construction and equipment capital costs and operating costs per tonne processed at the facilities in the recycling chain. A value-chain analysis used to evaluate recycling costs and benefits ERRA (2000) will evaluate the cost of each activity according to generally accepted accounting principles to establish net cost, where the sales price of recycled material is included.

As we saw in Chapter 3.3.2, SETAC (2004) has established a working group whose aim is to clarify aspects of, and to propose a framework for life cycle costing (LCC). In this approach all costs associated with the life cycle of a product covered by supplier, producer, users and end-of-life actors is added to quantify total cost. This approach seems also reasonable to apply when calculating the economic performance of the Resirk/PET system. However, in order to emphasize that there are also benefits connected to recycling and other waste management options, the cost of alternative raw material, given by the purchase price (excl. VAT) should be included. Hence *net* cost could be a good indicator for waste management evaluation, and it includes the sum of all direct costs (excluded externalities) associated with waste management subtracted avoided cost of alternative raw material:

$$Net\ cost = \sum_i (Running\ cost + Administration\ cost)) - Avoided\ cost$$

where *i* expresses the cost bearers in the Resirk/PET system

Another argument to apply net cost in this way is the fact that the data availability is good and that Norsk Resirk includes these types of cost in their balance account.

As we can see in Appendix D, to compare eco-efficiency from one year to the next, costs and avoided costs are adjusted for inflation by relating them to the value in 2000. It is assumed that the annual inflation between 2000 and 2003 was 2.5 %.

In SETAC's LCC approach there are no standards on which types of costs to include or whose costs to include. However, as we saw in Table 3.1 in Section 3.3.2, SETAC suggests four questions to answer to specify and clarify what LCC dimensions one applies. In the table below I have shown which costs and whose costs I have included, and how the costs are quantified and aggregated.

Dimensions	Questions	Selection
Cost categories	Which costs will be included?	Administration cost, running cost
Cost bearers	Whose costs will be included?	Norsk Resirk's, reclaimer's and end user's avoided cost
Cost models	How are the effects quantified?	Steady state
Cost aggregation	How are the results aggregated?	Average yearly cost, Value in year 2000

Table 4.1: Selection of cost dimensions in the study of the Resirk/PET system's net cost.

Before going to the next indicator I will briefly explain why I have not included the money flows of reduced packaging tax (due to increased return rate), deposit (and non-claimed deposit) on PET bottles, and administration fee in the economic influence indicator. Incomes from non-claimed deposit and administration fee cover Norsk Resirk's costs, and increased non-claimed deposit can results in lower administration fee. Some may argue that these money flows should be included since these are more relevant for actors such as, for example, producers and importers. Their savings due to reduced packaging fee on a PET bottle in the Resort system by far outweigh the administration fee they have to pay for each bottle they introduce into the system. However, I am concerned about life cycle cost here, i.e. the net cost of transferring used bottles into PET flakes, heat, or waste at landfill, and not the money flows in and out of Norsk Resirk. Besides, for producers and importers (and hence consumers) it will also be desirable to pay as low an administration fee as possible. The ultimate aim of the system would hence be to ensure the highest possible recycling rate at the lowest possible net cost.

Net GHG emissions as environmental influence indicator

In chapter 1 we saw that Lerche Raadal et al (2003) have done an LCA analysis on recycling of PET bottles in the Resirk system. According to this study there is a correlation between the system's greenhouse gas (GHG) emissions and other environmental impact categories. As this thesis builds on the Lerche Raadal study, it should be fair to restrict the number of environmental influence indicators to only one, net greenhouse gas (GHG) emissions, calculated as net emissions of CO_2 equivalents (net CO_2e). However, the selection of this indicator can also be justified from an environmental relevance point of view. This indicator, suggested by WBSCD as one of several appropriate generally applicable indicators, includes the amount of GHG emissions released to air from fuel combustion, process reactions and treatment processes. It includes the greenhouse gases CO_2, CH_4, N_2O, HFCs, PFCs and SF_6, and is given as metric tonnes of CO_2e (WBCSD 2000), see Appendix E for the various gases global warming potential. The climate changes caused by the increasing concentrations of greenhouse gases are perhaps the most discussed environmental issue these days. Due to the February 2005 entry into force of the Kyoto protocol (UNFCCC 1997) on reduction of climate gases, climate challenges will most likely continue to be a highly relevant environmental issue for a long time. Resirk and other waste management systems will contribute to CO_2e emissions, particularly from transportation and re-processing. However, the overall CO_2e balance of waste management systems with a substantial amount recycling of carbon intensive waste will in most cases be negative. The reason is very simple; it is often assumed that the secondary raw material produced in a recycling loop is applied as an alternative to virgin material, which gives more emissions than secondary raw material to produce. This is the reason for including the term *net* in this indicator. This environmental influence indicator can be calculated by using the following formula:

$$\textit{Net GHG emissions} = \textit{Waste management emissions} - \textit{Avoided emissions}$$

4.2.3 Goal and scope of eco-efficiency study

In phase 1 in LCA and LCC, the basis methods for eco-efficiency calculation in this thesis, the goal and scope of a study must be defined. This approach is also applied in the study of the eco-efficiency of the Resirk system.

Purpose of analysis/application of indicators

The purpose of this eco-efficiency study is to analyse how the eco-efficiency of the Norwegian deposit- and recycling system, the Resirk system, for PET bottles, has changed from start up in 2000 until the end of 2003, and thereafter to find important factors influencing on the eco-efficiency. The eco-efficiency calculations are based on Norsk Resirk's mission, may be used for internal improvements, and is calculated on an annual basis.

Functional unit

As shown in the previous section, Norsk Resirk's mission and perspective is to arrange a deposit system where participating PET bottles are recycled in an economical and environmentally preferable way. This can be argued to be the function of the Resirk system. However, as the Resirk/PET system also comprises those deposit bottles that are not returned for recycling and hence managed by other waste management solutions, this should also be reflected in the functional unit. I would argue that the following functional unit is appropriate for quantification of net cost and net GHG emissions:

> *Reclaiming, energy recovery, and landfilling of 1000 kg PET bottles from consumption in the Norwegian deposit system.*

The system will be studied for the 2000-2003 period. In order to give a more complete picture of the efficiency of the system, the return rate and recycling rate will also be presented.

System boundaries

In order to quantify the eco-efficiency of the Resirk/PET system, the system boundary must be specified. In many respects, Norsk Resirk is, as presented in chapter 2, somehow involved in most parts of the life cycle of the PET bottles, not only the waste management. They decide to a certain extent the design and material specification of the bottles and they demand administration fees from producers and fillers of PET bottles sold in the market. Hence, it could have been appropriate to include these upstream elements to quantify eco-efficiency. However, based on their mission I would argue that Norsk Resirk is mainly concerned about the destiny of the bottles after they are consumed. Administration fees and, in particular, design and material specification for bottles are rather means to achieve eco-efficient recycling. A weakness, however, when defining used PET bottles as the upper system boundary is the fact that the amount of used bottles generated is not reflected in the eco-efficiency calculations. However**,** interviewees at Norsk Resirk have revealed that reduction of the amount of used PET bottles to be generated, i.e. waste minimization is not a goal in the Resirk/PET system. On the contrary, Norsk Resirk argues that it would be preferable, both from an economic and environmental point of view, to increase the number of beverage types and hence packaging volume in the Resirk/PET system at the expense of alternative systems for distribution and recycling of beverage packaging in Norway.

Figure 4.1 below shows the defined system boundary. The upper system boundary is where PET bottles are consumed, whereas the lower system boundary includes production of PET flake raw material, and use of PET bottles, in combination with other household waste, for heat production. Some bottles are not recovered at all; they are deposited at landfills. As we can see, avoided production of alternative raw material and from alternative fuel are also included within the system boundaries.

If going more in to detail, we can see that he system boundary is defined to embrace the sum of costs and sum of GHG emissions for returning (buying and consumption is as we can see beyond the system boundary) the used PET bottles, organizing deposit facilities for used PET bottles (reverse vending machines or manual solutions), transport ("Tr" in the figure") from shop to warehouse, further transport to baling depot, the process of sorting and baling of PET bottles, transport of PET bale to reclaimer, and, finally the costs and GHG emissions of production and delivery and PET flakes. Moreover the costs and GHG emissions of transport of not returned bottles from households to landfill and incineration, as well as of the treatment of landfill and incineration are included. The only avoided costs and emissions come from production of alternative raw materials and from use of oil for heat production.

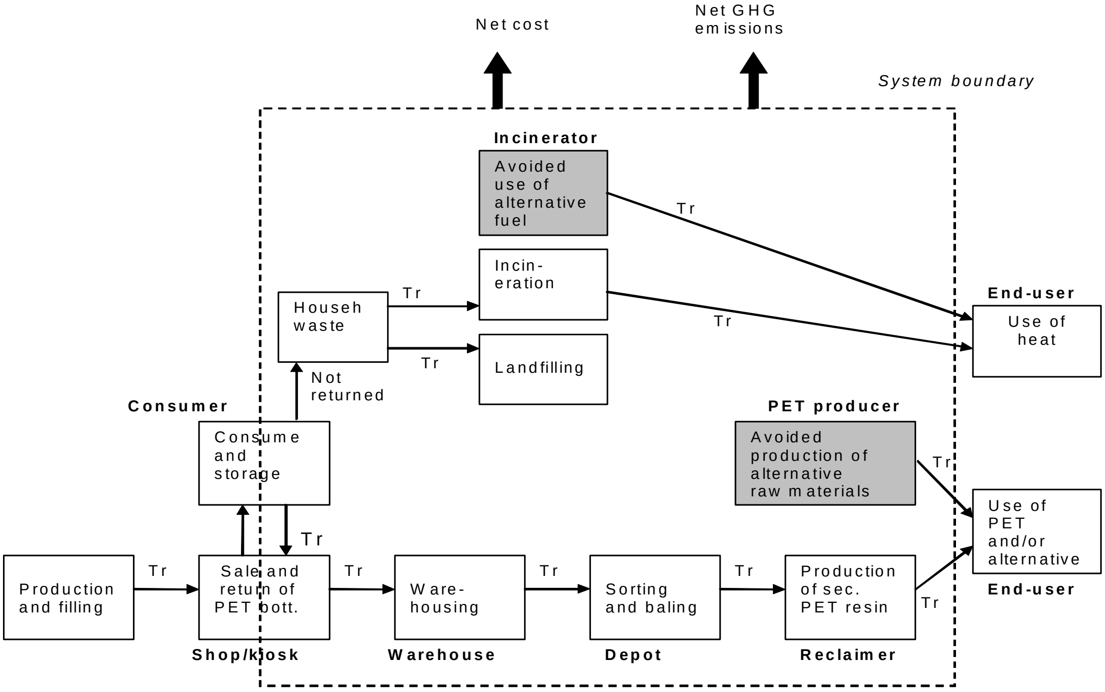

Figure 4.1: System boundary for quantification of eco-efficiency for recycling, incineration and landfilling of PET bottles in the Resirk/PET system 2000-2003

4.2.4 Calculation of eco-efficiency

Above we have seen that net cost and net GHG emissions seem to cover relevant economical and environmental aspects of waste management of used PET bottles in Resirk system, and that these two indicators seem to give a good picture of the system's eco-efficiency. In the eco-efficiency equation of the ratio between the environmental influence and cost, presented it in the beginning in of this chapter, the basic thinking is that the higher eco-efficiency value the better. This can be acquired by improving the environmental influence and/or reducing the cost. By doing so, one can easily compare a given process or product from one year to the next, or making eco-efficiency comparison between various processes or products. However, when applying the net cost and the GHG emission indicators and defining the system border to include used PET bottles as upper system boundaries and use of secondary raw material or PET bottles for incineration as lower system boundaries, this way of thinking could create some difficulties. In waste management systems the net cost per are almost always positive (i.e. costs of bottles going to landfill and for production of secondary raw material and heat are higher then the avoided costs). The net GHG emissions, on the other hand, are usually negative (i.e. avoided emissions from alternative production of heat and raw material excess emissions from the waste management system). Increased eco-efficiency is obtained if the denominator net cost per functional unit (FU) decreases and/or the nominator of Net GHG emissions per FU increases. Hence, to ensure that eco-efficiency ratio gives “the higher eco-efficiency, the better Resirk/PET system”, we should change the eco-efficiency equation to:

$$Eco\text{-}efficiency \equiv \frac{Environmental\ influence}{Cost} \equiv -\frac{Net\ GHG\ emissions}{Net\ cost} = -\frac{{}^{CO2e}\!/_{FU}}{{}^{€}\!/_{FU}} = -\left[\frac{CO2e}{€}\right]$$

Increasing ratio means increased eco-efficiency. This equation is valid for net GHG emissions < 0 and net cost > 0.

4.2.5 Assumptions and sources

In this section I will present the most important assumptions and data sources applied in this eco-efficiency study. For a complete overview, including calculations, see Appendix D.

Material flow
The annual generation of used bottles is set to equal the annual sales of bottles (Resirk 2000-2003).

In order to find the total mass of the used bottles, the average weight of the individual bottles must be found. This weight, found to be 35g in 2000 and 2001 and 35.7g in 2002 and 2003, is used to calculate metric tonnes registered sales of bottles from producer and importers, as well as metric tonnes RVM- and petimeter registered bottles returned by consumers to shops in the years 2000-2003.

The recycling rate relative to the return rate is based on a previous LCA study of recyclable and refillable PET bottles used in beverage packaging in Norway (Lerche Raadal et al 2003). In this study it is estimated that 4 % of the mass of the returned bottles is lost before becoming the secondary raw material of PET flake, see appendix D for annual recycling rates.

It is assumed that all PET bottles not being returned in shops will be put in the waste bin in households and thereafter be energy recovered or end up at landfills. It is assumed that 67 % of this household waste fraction was deposited at landfill and that 33 % was energy recovered in 2000-2003 (Statistics Norway 2001).

Net cost

Net cost, the indicator for economical efficiency of the system, is found by adding costs from all stages involved in recycling, energy recovery and landfill of 1000 kg consumed PET bottles, subtracted avoided costs of the alternative material- and energy replaced. The avoided costs of the alternative material are set to equal the material's sales price.

The costs are divided into:

- costs of transporting used bottles to shop
- costs of producing PET bales from used bottles
- costs of producing PET flakes from PET bales
- costs of incineration of used PET bottles
- costs of landfill of used PET bottles
- avoided cost of alternative raw material
- avoided cost of alternative fuel for incineration.

Costs of transporting used bottles to shop

I assume no costs from this activity since the reason for consumers to drive to the shop is to do shopping, not to return the bottles. (Lerche Raadal et al 2003)

Costs of producing PET bales from used PET bottles

The various costs involved to produce the bales are solely based on Norsk Resirk's annual account, and are calculated on the basis of their internal allocation methods which are mainly based on a combination of volume and mass of bottles and cans handled (Norsk Resirk 2000-2003).

Costs of producing PET flake from PET bales

Unfortunately, costs data for the reclaiming process of producing PET flake, the secondary raw material and final product of the recycling system, are not accessible. However, if we assume that the reclaimer has a margin of 10 %, the costs of reclaiming can be found by the following equation:

Reclaiming costs = PET flake price (delivered) – PET bale price (delivered) – 10 %

The PET bale price is found in Norsk Resirk's annual accounts, while the PET flake price is based on average European prices (PCI reports 2000-2004).

Costs of incineration of used PET bottles

This cost element includes the costs of transport of PET bottles to the incineration plant and the cost of incineration of the bottles. Distribution of district heating is not included. For more information about these costs, see Appendix D.

Costs of landfill of used PET bottles

This cost element includes the costs of transport of PET bottles to the landfill and operation costs of the landfill. For more information about these costs, see Appendix D

Avoided cost of alternative raw material

According to the reclaimer, who has received PET bales from the Resirk/PET system since the system was established, 15 % of the secondary PET material produced in the Resirk system will replace recycled steel in the production of strapping, whereas 85 % will replace PET for production of packaging or fibre products. It is assumed that average European PET raw material replaced consists of 75 % virgin material and 25 % secondary material. It is moreover assumed that the secondary raw material produced in the Resirk system has the same quality and hence has the same wide user area as the virgin material (Lerche Raadal et al 2003).

The avoided costs are calculated on the basis of the sales price (excl. Value Added Tax (VAT)) of the raw material replaced. In this case it is based on the average annual European market price (delivered) for PET flake (secondary material) and for PET virgin (primary material) in 2000-2003 (PCI reports 2000-2004), as well as for sorted and baled steel cans (secondary steel) directly applicable for re-melting and production of strapping (WNDR 2005**)**.

Avoided cost of alternative fuel for incineration with energy production.

Avoided cost of alternative fuel at the waste incinerators is given in Appendix D.
It is assumed that waste incinerators with energy recovery apply oil as an alternative to incoming PET bottles (TEV 2001). Hence the price of oil is the avoided cost when PET bottles are incinerated.

Net GHG emissions

Net greenhouse gas (GHG) emissions, the indicator for environmental efficiency of the PET bottles in the Resirk/PET system, is found by adding greenhouse gas emissions from all stages involved in recycling, energy recovery and landfill of 1000 kg consumed PET bottles, subtracted avoided emissions from the alternative material- and energy production replaced:

- GHG emissions from transport, RVM and baling
- GHG emissions from flake production
- GHG emissions from incineration
- GHG emissions from landfill
- GHG emissions from avoided oil production
- GHG emissions from avoided raw material production

GHG emissions from transport, RVM and baling

Data is provided by Lerche Raadal et al (2003) unless otherwise specified. The following stages are included:

- Return of used bottles at shop
- Transport from shops to wholesalers
- Transport from wholesalers to baling depot
- Transport form baling depot to reclaimer
- Sorting and baling at depot
- Transport from households to incineration/landfills (Eik et al 2002)

For more information about calculations and data, see Appendix D

GHG emission from production of PET flake

It is assumed that emissions of CO_2e per kg produced PET flake from PET bale in the Resirk/PET system in 2000, 2001, 2002 and 2003 are similar to CO_2e/kg in Eik et al (2002).

GHG emission from incineration

It is assumed that emissions of CO_2e per kg incinerated PET bottles in the Resirk/PET system in 2000, 2001, 2002 and 2003 are similar to CO_2e/kg in Lerche Raadal et al (2003).

GHG emission from landfill

Degradation of PET bottles into CO_2 (aerobic degradation) or CH_4 (anaerobic degradation) is an extremely slow process which will take several hundreds of years. These emissions are therefore not included in this study.

Avoided GHG emissions from alternative raw material production

As mentioned above it is assumed that 85 % of the PET flakes produced in the Resirk system replace use of alternative PET raw material (75 % virgin and 25 % recycled), whereas 15 % of substitute production of secondary steel. It is further assumed that avoided emissions of CO_2e per kg replaced in the Resirk/PET system in 2000, 2001, 2002 and 2003 is similar to CO_2e per kg in Lerche Raadal et al (2003). The CO_2e found in this stage is based on Lerche Raadal et al (2001).

Avoided GHG emissions from alternative fuel

It is assumed that avoided emissions of CO_2e/kg replaced oil in the Resirk/PET system in 2000, 2001, 2002 and 2003 are similar to CO_2e/kg found in Raadal et al (2001). Fore more information and data, see Appendix D.

4.3 Delimitations and assumptions in the study of interactive resource development

In this section I will present the assumptions and delimitations I have made in order to carry out the interactive resource development analysis in chapter 5.2. A specific emphasis will be given to description of the selected resources.

4.3.1 The focal resource

In order to study resources in a network a starting point, a focal resource, must be defined, see 3.4.4. This is the resource that is studied most in detail, however, as we will see in chapter 5.2, such a network analysis also implies that development of interrelated resources are analysed. I have defined the product of the bottled non-carbonated mineral water Imsdal to be the focal resource in this study. In fact, there are no strict criteria for what the selection of the focal resource should be based on. However, I have tried to justify my choice on the basis of two reasons:

- The bottle mix of the Resirk/PET system in 2000-2003 contained on average almost 20 % Imsdal bottles, meaning that these bottles, were by far the largest bottle fraction in the system
- Imsdal was hit by an interesting piece of sabotage in August 2002, which had an impact on both Imsdal as well as other directly and indirectly connected resources.

The non-carbonated mineral water Imsdal is gathered from an underground source in the Norwegian valley Imsdalen, located 250 km north of Oslo. The water is naturally filtered through sand materials before ending up in the underground source where it has a year-round, constant temperature of 5 ^{0} C. Commercial tapping from the source started in 1971, but the source were exploited and kept as a secret among fishermen and hunters long before that. Ringnes AS bought the rights to the source in 1987, and the non-carbonated water was launched in 1994 under the name Imsdal.

Today, Imsdal beverage is mainly tapped into three different bottles: 0.5 liter, 0.6 liter and 1.5 liter one-way PET bottles. All these bottles are filled on the same tapping line. In addition, 5 liters and 18.9 liters containers are filled on Ringnes' second Imsdal tapping line. In this analysis I will mainly focus on the bottles that are participating in the Resirk/PET system, i.e. the Imsdal tapped on 0.5 liter, 0.6 liter, and 1.5 liter PET bottles. The focal product of Imsdal, hereafter referred to as just Imsdal, can be defined to have four different features: beverage, bottle (referred to as Imsdal bottle), cap and label. Figure 4.2 below shows the 0.6 liter Imsdal sports bottle.

Figure 4.2: The 0.6 liter Imsdal sports bottle

4.3.2 What resources are included in the defined network?

After having defined the focal resource, it is time to decide what other resources to include in the resource network to study. Similarly as when defining the system boundaries for the eco-efficiency analysis, resources to be included (and hence resources to be excluded) must be defined.

As "everything is connected to everything[11]" many various types of resources will have an influence on the development of a focal resource such as the Imsdal. Moreover, some of these resources will combine with each other as well as with other (unknown) resources. A delimitation of what resources and resource interfaces to study is hence needed. This can be done by isolating a few resources and interfaces which are studied in detail. Figure 4.3 shows the focal resource of Imsdal (marked blue) and some of the other products, facilities, business unit, and business relationships (marked grey) that have an impact on, and are influenced by, Imsdal. The arrows (apart from the thick business relationship arrows) indicate the resource interfaces between two resource elements. In addition to the focal resource, three other resources are selected for a detailed study: Ringnes AS, the PET spec, and the PET bales. As we will see in Chapter 5.2 all these resources had an influence on and were influenced by the Imsdal resource, and moreover they had, through interactive development of Imsdal, an impact on the eco-efficiency of the Resirk/PET system. Two of the interfaces will be isolated and studied in detail: the interface between Imsdal and Ringnes and the interface between the PET spec and the PET bales (the red arrows in the figure).

Even though not shown specifically in this thesis, it must be noted that I studied a larger part of Imsdal's resource structure before I chose the abovementioned resources and resource interfaces for a detailed study. This pre-screening of the resource structure

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[11] As former Norwegian Primer Minister Gro Harlem Brundland once put it to explain a particular incident.

allowed me to select some of the resources I believe had an influence on the development of Imsdal. By doing this, I have avoided the risk of carrying out a detailed study of resources that are not central for the development of Imsdal.

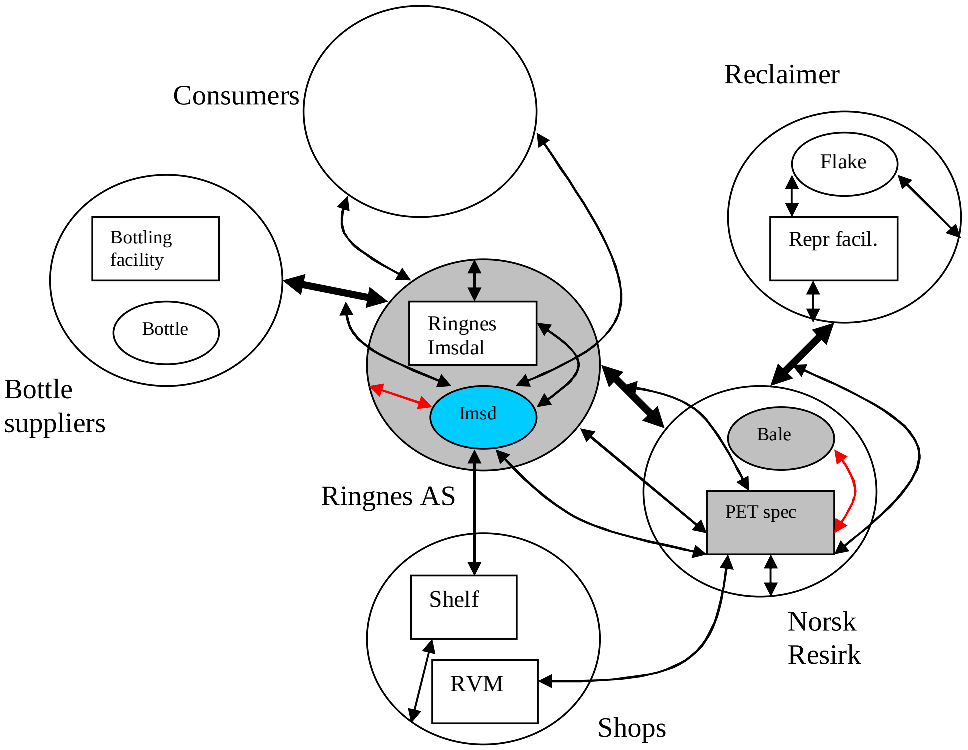

Figure 4.3: Parts of the focal resource Imsdal's network of resources and resource interfaces

4.3.3 Selected resources: Ringnes AS, PET spec, and PET bale

The business unit Ringnes AS, which had a turnover of 5 billion NOK (650 million €) in 2002 and a Norwegian market share of 60 %, 70 %, 30 % on beer, mineral water and soft drinks, respectively is, at the time of writing, owned by the Danish company Carlsberg. The production facility for Imsdal, Ringnes Imsdal, is one of seven Norwegian Ringnes AS breweries and plants. Ringnes does not define Ringnes Imsdal to be a separate business unit even though there were around 15 employees at Ringnes Imsdal autumn 2003. That is why I define Ringnes, and not Ringnes Imsdal, as the business unit to analyse in this thesis. However, it must be noted that I am only concerned about those parts of Ringnes that are connected to the Imsdal product. In addition to being defined as a business unit resource, Ringnes is an actor which interacts with actors. Interactions between actors influence on how resources adapt in relation to each other. Hence, the actor Ringens will through interactions with actors influence on the business unit Ringnes and other resource this business unit is interrelated with. In this thesis I am mostly concerned about Ringnes as a business unit resource.

The facility of the PET spec decides what type of bottles to allow in the Resirk/PET system. The spec has mainly two functions:

- To ensure *acceptance* in reverse vending machines in shops or, alternatively, in petimeters at warehouses by giving requirements on bottle shape, readability of barcodes, as well as on minimum and maximum size of the bottles.
- To ensure good *PET bale quality* by specifying what type of bottle- and cap material, label, and label glue to accept.

When making a spec Norsk Resirk has to decide to what extent it should be rigid spec or a more open one. A rigid spec, only allowing certain type of bottles to enter the system, will cause fewer problems for RVMs and petimeters, in addition to ensure good bale quality. A rigid spec may hence increase the eco-efficiency of a recycling system. If, on the other hand, having a loose spec, which opens up for different shapes and materials, problems could for instance appear if the bottle is not cylindrical. In such a case, the RVM and petimeters will not able to rotate the bottle and read the barcode on the label. Moreover, a loose spec which for example accepts PVC bottles, may give a PET bale quality which could, at worst, be rejected by reclaimers and hence have little or no market value. In this case recycling of the returned bottles will possibly not take place at all. However, limitations given in a strict spec will limit the freedom of bottle design among producers. Importers, which to a far lesser degree have the opportunity to influence on the design of the bottles since this is often decided by large producers abroad, are also affected since they will not be allowed to import bottles which not fulfill the rigid spec. One advantage for the producers and importers of having a strict and clear spec, however, is that they are well aware of what bottle types they can, and cannot, make or import.

The PET bale could be defined to be an intermediate product of the Resirk/PET system. It is a commodity, consisting of collected, sorted and compacted bottles which the business unit Norsk Resirk sells to reclaimers abroad. The price they get for this 300-400 kg and 1.5-3 m^3 rectangular physical product is dependent on various factors such as international oil price, seasonal beverage consumption variations and not at least, what we are concerned about here, the quality of the bale. The quality of the intermediate product PET bale has an influence on the possibility and cost of producing quality PET flake, the secondary raw material and the final product of the Resirk system.

4.3.4 Selected resource interfaces

The business unit Ringnes is the owner and producer of the product Imsdal. Imsdal is an important product for Ringnes' incomes as well as for the business unit's identity. Hence the two resource elements are directly connected to each other through a resource interface. As we can see from Figure 4.3 in 4.3.2, Imsdal also has important interfaces with for example the business relationship between Ringnes and bottle suppliers, as well as with the PET spec. Ringnes is connected to resources such as the business unit consumer and Ringnes Imsdal production facility.

There is an important interface between the PET spec and the PET bottles trying to enter the Resirk/PET system since the spec decides what bottles to allow in the system. However, it should be mentioned that the spec has interfaces with other resource elements as well. Among several, it will also be connected to reverse vending machines (RVMs) which must be taken into account when making a spec, the producer and importers which actively use the spec, and to the PET bale, see Figure 4.3 in 4.3.2. The second interface to study in detail is the one between PET bale and PET spec. The spec and the bale are connected since one important purpose of the spec is to ensure good bale quality. Ideally, the two resources should be connected and interact in such a way that they are fully adapted all the time. The bale should give input to what requirements the spec should contain to ensure good bale quality and the spec should change in accordance with this. However, as we will see in chapter 5 this is not necessarily always the case.

4.4 Data collection methods

In this section I will briefly present the methods I have applied to gather data for analysis of eco-efficiency and interactive development of resources. Basically I have applied two different data collection methods; literature search and qualitative research interview. In Figure 4.2 on the next page, the various literature sources are shown in four of the columns (laws and directives, reports and annual accounts, scientific papers and books, internet sources). All these types of sources are presented in the reference list. The data collection method of qualitative research interviews, shown in the far right column, is based on suggestions made by Kvale (1996). Interviews are carried out by applying a semi-structured approach. Instead of using a rigid research guide with a specified number of questions to ask, the interviews were rather characterized by dialogues where issues related to various aspects of the Resirk/PET system were raised and discussed. I have had 18 such interviews with (anonymous) representatives from:

- Norwegian Authority for Pollution Control
- Norwegian Ministry of Environment
- Norsk Resirk AS
- Beverage producer Ringnes
- Beverage producer Coca Cola, Norway
- RVM supplier Tomra Systems ASA
- Reclaimer Expladan, Denmark
- Waste section at the municipality of Trondheim, Norway
- Responsible for sorting and landfill Trondheim Renholdsverk,
- Incineration plant Trondheim Energiverk

All interviews were taped, transcribed and interpreted.

In the column on the left hand side the procedures for carrying out the eco-efficiency analysis are shown. The definition of goal and scope, identification of the Resirk/PET system's material flow, as well as search for environmental- and economical data is a part of the eco-efficiency analysis, whereas definition of resource network and identification of resources, resource interfaces and interaction is carried out in the analysis of interactive resource development. As we can see, scientific papers and books, and reports and annual accounts, are the dominant literature sources applied. Information gathered from the interviews were used for all purposes apart from the procedure of searching for economical- and environmental data

	Laws and directives	Reports and annual accounts	Scientific papers and books	Internet sources	Interviews
Define goal and scope of eco-efficiency analysis	x	X	X		x
Identify material flow		X	X		x
Find economical data			X	X	
Find environmental data		X	X	X	
Define network		X	X		x
Identify resources		X	X		x
Identify resource interfaces			X		x
Identify interaction			X		X

Table 4.2: Data collection methods applied to carry out procedures of the eco-efficiency- and interactive resource development analysis

5. Analysis and results

After presenting the case, the theory, and the methodological choices of my thesis, it is time to conduct the analysis and report my findings. In the first part of this chapter, I will quantify eco-efficiency changes of the Resirk/PET system in the 2000-2003 period, briefly compare the quantified eco-efficiency with other systems, and, finally, I will identify most contributing parameters to eco-efficiency. In the second part, 5.2, I will analyse how Imsdal, the largest bottle fraction in the Resirk/PET system, has interactively developed, and further, discuss how this change has influenced on the contributing factors to eco-efficiency between 2000 and 2003.

5.1 *Eco efficiency analysis*

As mentioned above, an important aim of this thesis is to examine how the economic and environmental efficiency (eco-efficiency) of waste management of the PET bottles in the Resirk/PET system has changed from start up in May 2000 until the end of 2003, and moreover to find which parameters have had the largest influence on this eco-efficiency. This eco-efficiency analysis is divided into five sections; presentation of material flow, costs quantification, calculations of greenhouse gas (GHG) emissions, eco-efficiency evaluations, and, finally, a summary of which parameters have contributed most to eco-efficiency.

5.1.1 Material flows

Table 5.1 below shows how sales, return rate, and, grey shaded, how much of the returned material fractions that have gone to recycling, energy recovery, or landfill, respectively. Numbers are given for the period from the first bottles were deposited in May 2000 until the end of 2003.

Year	Sold bottles [tonnes]	Return rate [%]	Recycling [%]	Energy recovery [%]	Landfill [%]
2000	351	29,6	28,4	23,6	48,0
2001	771	56,3	54,0	15,2	30,8
2002	1588	65,2	62,6	12,3	25,1
2003	1695	75,0	72,0	9,2	18,8

Table 5.1: Consumption, return, recycling, energy recovery, and landfill of PET bottles in the Resirk/PET system 2000-2003.

As we see in the table, the amount of bottles sold (and hence consumed), have increased significantly every year, apart from 2002 to 2003 when it only increased by 6.3 %. There are several reasons for the increased consumption of PET bottles in the Resirk/PET system. The most important is probably the fact that more producers, and especially importers, have been increasingly aware of the tax reduction on one-way PET bottles when participating in the Resirk/PET system, see chapter 2.2 for description of this taxation system. Another important explanation is the global trend of more use of PET for beverage purposes at the expense of other materials such as glass. A third reason is the steadily increasing consumption of beverage products such as mineral water and carbonated soft drinks, which very often are filled on single use PET bottles.

When it comes to the return rate, the increase can mainly be explained by improved knowledge and awareness among the consumers. Before the establishment of the deposit system Resirk/PET in May 2000 there was no deposit on the very few one-way PET bottles in the Norwegian beverage market. Hence consumers were not used to thinking of single use PET bottles as deposit bottles in the same way as for example glass bottles. However, as time went by after May 2000, consumers became more and more aware of the new PET bottles and, moreover, they discovered to an increasingly degree that they had to look for the deposit label to find out whether there is deposit on a particular bottle. However, the return rate for PET bottles did not reach as high as the deposit cans in the Resirk/PET system did. Actually, the return rate of the cans have been above 90 % every year since the system was established in 1999. One reason for this is probably that while the cans from various producers and importers more or less look the same in terms of shape and size, the appearance of the bottles changes from one bottle to the next, making it difficult for the consumer to recognise the new bottles that are coming into the market.

5.1.2 Net cost

As shown in the previous chapter the net cost of the functional unit of reclaiming, incineration and landfill of 1000 kg used PET bottles in 2000, 2001, 2002, and 2003 is calculated by adding costs of collection, transport, sorting, reclaiming, incineration and landfill, then subtracting the avoided costs of use of alternative energy and alternative raw material.

In order to give a better understanding of the various cost elements, the presentation of the costs will be divided into:

- Costs of producing PET bales from used PET bottles
- Costs of producing PET flakes from PET bales
- Costs of incineration and landfill of used PET bottles
- Avoided costs from alternative production
- Net cost

Costs of producing PET bales

All PET bottles that are returned in the shops are transported and sorted, before being compacted into PET bales which are delivered to the reclaimer. In Figure 5.1 below the annual costs (running costs and administration costs) of producing PET bales from 1000 kg used PET bottles are presented. Delivery of the PET bales to the reclaimer’s gate is included. As we can see the costs were significantly higher in 2000 and 2001 (around 4000 € per 1000 kg consumed bottles) than they were in 2002 and 2003 (around 3000 €) despite of higher return rates, and hence more bottles to handle through the recycling loop, in the latter years. Due to the increase in return rate every year, it is not surprising that the running costs of producing PET bales also have increased. However, the running costs have not gone up by the same extent as the return rate. The return rate increased for example from 56.3 % in 2001 to 75 % in 2003, while the running costs remained almost unchanged. If looking at the administration costs, we can see that they were reduced every year between 2000 and 2003, with a 50 % reduction from 2001 and 2002 as the most notable observation.

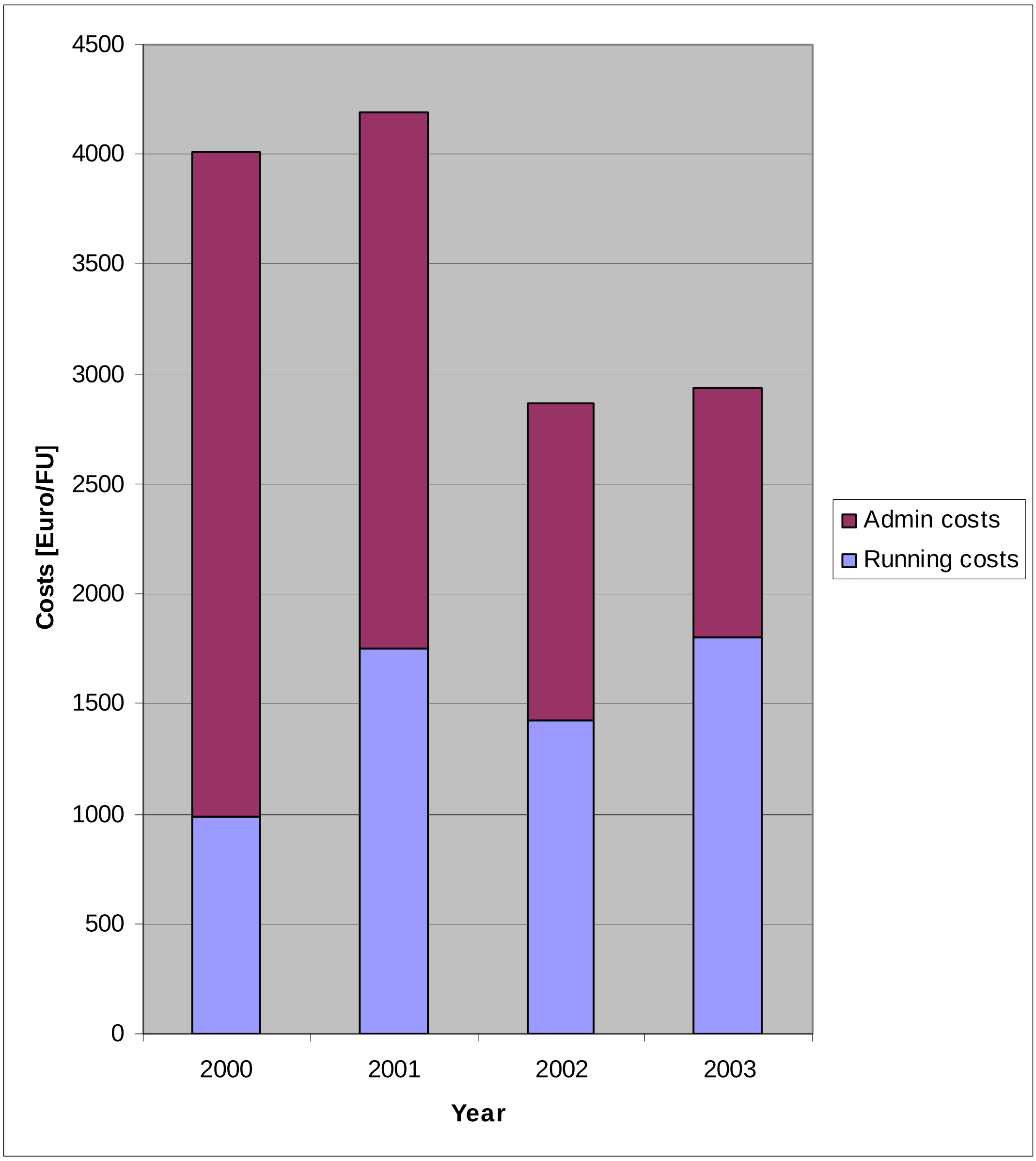

Figure 5.1: Administration costs and running costs of producing PET bales from 1000 kg used PET bottles in the Resirk/PET system in the years 2000-2003

These results tell us three important things: Firstly that it takes time to gain experience to develop a mature economical efficient system, secondly that an increased volume of bottles included in the system reduce the cost of PET bale production, and finally that increased return rate, and hence more bottles to handle through recycling per 1000 kg consumed, by no means necessarily leads to increased costs.

The generated amount of used bottles and return rate are the two factors that decide the input volume to the recycling system, and hence the possibility to come closer to a cost efficient large scale waste management system mainly based on recycling. As mentioned above, it was in particular the administration costs per functional unit that were reduced when the amount of input material for recycling increased. The running costs only showed a slight increase as the return rate went up. Increased cost due to the more input material to handled were probably almost equalised by better capacity utilization in reverse vending machines, trucks, and at the baling depots.

Among the administration costs it is in particular marketing and information costs that make a significant impact. One important reason for the high level of these costs is the fact that a substantial amount of money has been invested, especially in the start-up phase, to inform consumers about the opportunity to return the PET bottles and get the deposit refunded. This has not been an easy task, given the fact that there are a great variety of different bottle types which makes it difficult for the consumers to recognise the bottles as “deposit bottles”. Moreover, much emphasis has been put on informing producers and importers about the bottle’s design and material requirements, as well as about the rather costly approval procedure for bottles that are going to be a part of the system.

As shown in Table 5.2 the increasing degree of large scale effects, and corresponding reduction of running and administration cost per functional unit, has resulted in a significant reduction of the cost of producing one kg PET bale from one kg used PET bottles. While the bale cost in 2000 was 13.54 €/kg in 2000, it was reduced to 3.92 €/kg three years later.

	2000	2001	2002	2003
Bales produced [kg/FU]	296	563	652	750
Bale cost [€/FU]	4007	4190	2866	2937
Bale cost [€/kg]	13,54	7,44	4,40	3,92

Table 5.2: Cost of producing PET bales 2000-2003

Costs of producing secondary PET flakes

The costs of producing secondary PET flakes from PET bales in the period 2000-2003 are given in Table 5.3 below, and it includes costs of reclaiming and delivery of the PET flakes to the end user. As the production of PET flakes per 1000 kg bottles consumed has increased every year from 2000 to 2003, it is not surprising that the costs have increased accordingly. One reason for this is that the increasing amount of bottles coming from the Resirk system has not impacted significantly on the reclaimer’s production volume, which relies on other suppliers as well, and is hence more or less fixed. Contribution towards economy of scale effects in the Resirk/PET system will therefore not influence on the reclaimer's processing and transport costs.

	2000	2001	2002	2003
Flakes produced [kg/FU]	284	540	626	720
Flake cost [€/FU]	125	269	298	360

Table 5.3: Costs of producing PET flakes from PET bales, 2000-2003

Even though not reflected in the reclaiming costs calculated here, the quality of the incoming PET bale will have a significant impact on the reclaimer's cost of producing high quality PET flake. If receiving low quality PET bale, it must be invested in costly technology or man hours to sort the bales before reclaiming it into PET flakes. The material and design choices of the PET bottles, which decide the bottle mix and hence the quality of the PET bale, is central to ensure high PET bale quality, see chapter 5.2.

Costs of incineration and landfill

In Table 5.4 below the fraction of the 1000 kg consumed bottles that are going to landfill and to incineration with energy recovery is shown. Pick-up costs of waste from households to landfill/incineration and costs of incineration and of landfill are also given. Again it is worth noting that all these cost elements have, per functional unit, decreased as the return rate has increased and the amount of bottles going to landfill and incineration have been reduced accordingly. However, the Resirk/PET/ system increased volume of PET bottles in the 2000-2003 makes no contribution towards an increased large-scale effect for the costs of transport, of landfill, and of incineration of the total waste flow from households. The annual waste amount from households in Norway in 2000-2003 was around 1.5 million tonnes (Norwegian Ministry of Environment 2004) and 200-600 tonnes PET bottles in this waste fraction will therefore make little impact on the total waste costs, even though it should be mentioned that plastic in waste stream is important to increase the energy content of the waste to be incinerated to produce energy. It is assumed that the costs, per kg, transported, incinerated and deposited at landfills, were unchanged during the 2000-2003 period.

	2000	2001	2002	2003
PET to landfill [kg/FU]	480	308	251	188
PET to incineration [kg/FU]	236	152	123	92
Pick up costs [€/FU]	55	35	28	21
Landfill costs [€/FU]	64	42	36	27
Incineration costs [€/FU]	44	28	23	17
Sum costs [€/FU]	163	105	87	65

Table 5.4: Costs of PET bottles going to incineration and to landfill.

Avoided cost

As mentioned in chapter 4, it is assumed that secondary PET flakes produced in the Resirk/PET system and thereafter applied by end-users, replace an equivalent amount material mix of 15 % secondary steel, 85 % PET, which consists of 75 % primary (virgin) PET and 25 % secondary (reclaimed) PET. The PET bottles that are incinerated to produce district heating are replacing alternative use of oil at the waste incineration plant. It is assumed that the avoided costs are set to be equal to the purchase price (excl. VAT) of the replaced material. The table below shows avoided costs when replacing PET, steel, and oil.

	2000 [€/FU]	2001 [€/FU]	2002 [€/FU]	2003 [€/FU]
Primary PET	212	422	468	492
Secondary PET	33	49	72	92
Secondary steel	2	2	4	5
Oil	45	29	24	17
Total avoided	292	502	568	606

Table 5.5: Avoided costs of alternative PET, steel, and oil

Avoided cost has increased as a result of increased recycling rates through the period. Replacement of primary PET is as we can see, by far represents the largest savings. In fact primary PET resin for 492 €, or 82 % of the total avoided costs, were saved as a result of the reclaiming of 720 kg PET flakes in the Resirk/PET system in 2003. Moreover, we can see that the avoided steel costs hardly make an impact, while avoided use of oil contributed to 17 % of the total avoided cost in 2000 when the incineration rate was at its highest.

Net Cost

In Table 5.6 costs of producing bales, flakes, and energy from incineration, as well as the landfill cost are added, while avoided cost are subtracted to give the net costs of the functional unit of reclaiming, incineration, and dispose at landfill of 1000 kg used PET bottles in 2000, 2001, 2002, and 2003. Costs of transport are included in the various cost elements given in the table. As we can see the bale cost makes the highest impact on the net cost. Even in 2000, when the return rate was as low as 29.6 %, the costs of transferring used PET bottles into PET bales were by far the dominant cost element. Moreover, increased bottle consumption combined with higher return rates have reduced the costs of the Resirk/PET system; low consumption and return rate in 2000 and 2001 gave a net cost of almost 4000 €/FU, whereas larger volumes of bottles participating in the Resirk/PET system and improved willingness and ability among consumers to return the bottles in 2002 and 2003 resulted in lower costs. An important reason for the reduction in net costs is the increasing degree of economy of scale effects of transferring used bottles into PET bales.

	2000	2001	2002	2003
Recycled [kg/FU]	284	540	626	720
Bale cost [€/FU]	4007	4190	2866	2937
Flake cost [€/FU]	125	269	298	360
Cost incineration [€/FU]	63	40	33	25
Cost landfill [€/FU]	100	65	54	42
Avoided cost [€/FU]	- 292	- 502	- 568	- 606
Net cost [€/FU]	4003	4062	2683	2758

Table 5.6: Costs, avoided costs, and net costs

In Figure 5.2 the cost elements are, for illustration reasons, given in a bar diagram. As can easily be observed, the costs of making bales from consumed bottles are contributing most to the net cost, even though the reclaiming costs of making PET flakes from PET bales reached around 10 % of the net cost in 2003, compared to around 7 % in 2001. The costs of incineration and landfill made a small impact on the net costs. Even in 2000 when more than 70 % of the used PET bottles were incinerated or land-filled, these two waste management alternatives contributed to less than 4 % of the costs. The avoided costs, however, made a more significant impact; in 2003 the avoided costs comprised 18 % of the total costs of production of PET bales, production of PET flakes, incineration and landfill.

Experience gained after three and a half years operation of the Resirk/PET system has most likely made a significant contribution to the acquired cost reductions. However, as we have observed a slight increase of costs from 2002 to 2003, the question is to what extent further cost reductions are achievable with the current organization of the system. It may be that the net costs have stabilized around € 2700 per functional unit, and that it may be difficult to reduce costs significantly even though the sales volume and return rate continue to increase. However, there are ongoing discussions as to what extent the packaging fee on one-way packaging for beverages should be reduced or removed. According to Norsk Resirk this would result in a substantial volume increase of PET bottles in the Resirk/PET system, perhaps to a level of ten times as many bottles as there were in 2003. Real large scale-effect, involving considerable cost reduction of transport, sorting and baling could then be achieved. However, nothing is decided and the years to come will reveal whether considerable cost reduction will take place.

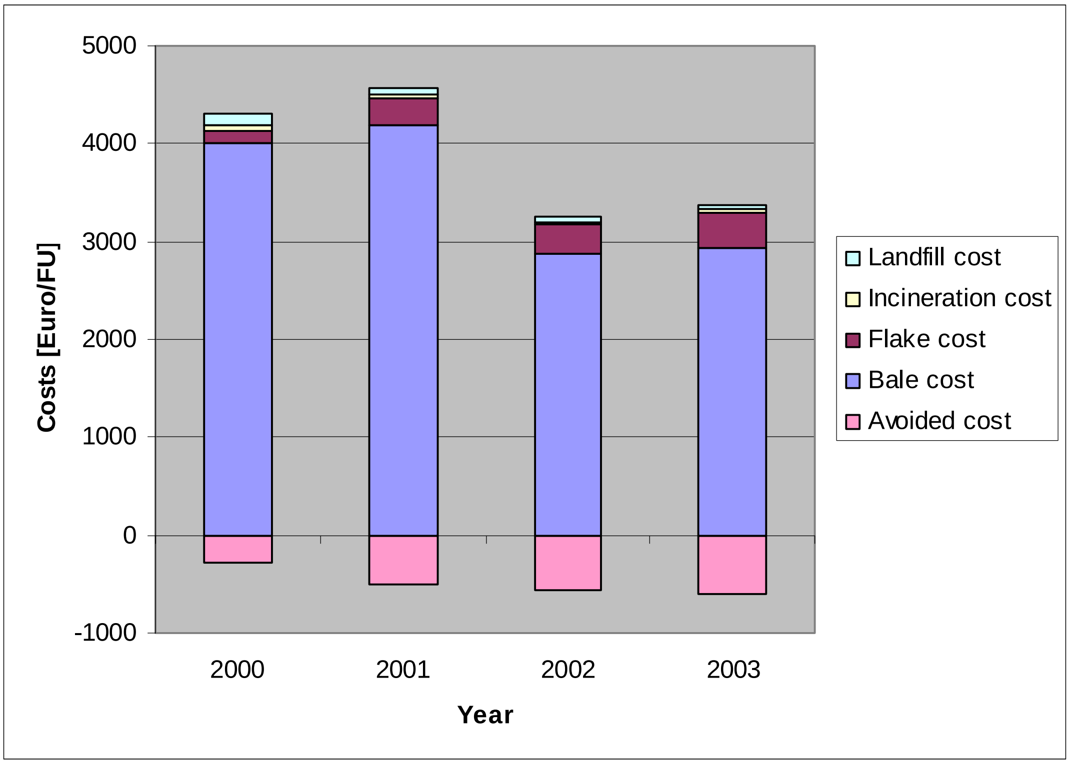

Figure 5.2: Costs, avoided costs, and net cost per FU [€/FU]

5.1.3 Net GHG emissions

The environmental efficiency of reclaiming, incineration and landfill of PET bottles in the Resirk/PET system is given by the net GHG emissions indicator. In Table 5.7 and Figure 5.3, both below, such emissions in the 2000-2003 period are given, and, as we can see, the net GHG emissions in all years are significantly negative. This means that emissions saved, the avoided emissions of alternative use of oil, PET and steel, were clearly higher than emissions from transport, RVM and petimeter operation, sorting, baling, flake production, and incineration. Hence the system had an environmental benefit, and as we can see this benefit has increased every year; in 2000 562 kg CO_2e were saved per 1000 kg bottles used, whereas 1442 kg CO_2e emissions where avoided as a result of the increased recycling rate to 72 % in 2003.

	2000 [kg CO_2e/FU]	2001 [kg CO_2e/FU]	2002 [kg CO_2e/FU]	2003 [kg CO_2e/FU]
Transport, RVM, baling	68	129	150	173
Flake production	77	146	170	195
Incineration	352	226	183	137
Avoided use of oil	-343	-220	-178	-133
Avoided use of PET and steel	-716	-1361	-1578	-1814
Net GHG emissions	-562	-1080	-1253	-1442

Table 5.7: Emissions and avoided emissions of GHG 2000-2003

In addition to the findings that increased recycling rate gives improved environmental performance, there are some other observations that are worth mentioning. First, it is worth noting that the largest fraction of the emissions comes from incineration (with the exception of 2003), while avoided alternative use of PET and steel raw material used for strapping give by far the largest environmental benefit. A second important observation is that recycling gives both less emissions as well as more avoided emissions compared to incineration with energy recovery. In 2000, for example, when 28.4 % of the bottles were recycled, while 23.6 % was incinerated, the emissions from incineration of bottles were almost five times as high as the emission from the flake production. Moreover, the avoided emissions from replacement of steel and PET were twice as high as the avoided emissions from alternative use of oil for energy production at the waste incinerator. A remarkable observation, which can been clearly seen in Figure 5.3, is the fact that the emissions from waste management of PET bottles were constant at around 500 kg CO_2e per 1000 kg consumed bottles in both 2000, 2001, 2002 and 2003. As the recycling rate increased, the emissions from transport, reverse vending machine and petimeter operations, sorting and baling, and flake production increased. However, at the same time the emissions from incineration decreased equally. Hence, it can be concluded that the from an emission point of view it is not important whether the bottles are recycled or incinerated, it is when it comes to the question of avoided emission that recycling is preferable to incineration. Another interesting observation is that for all years the emissions from incineration are almost equal to the avoided emissions from use of oil as alternative fuel.

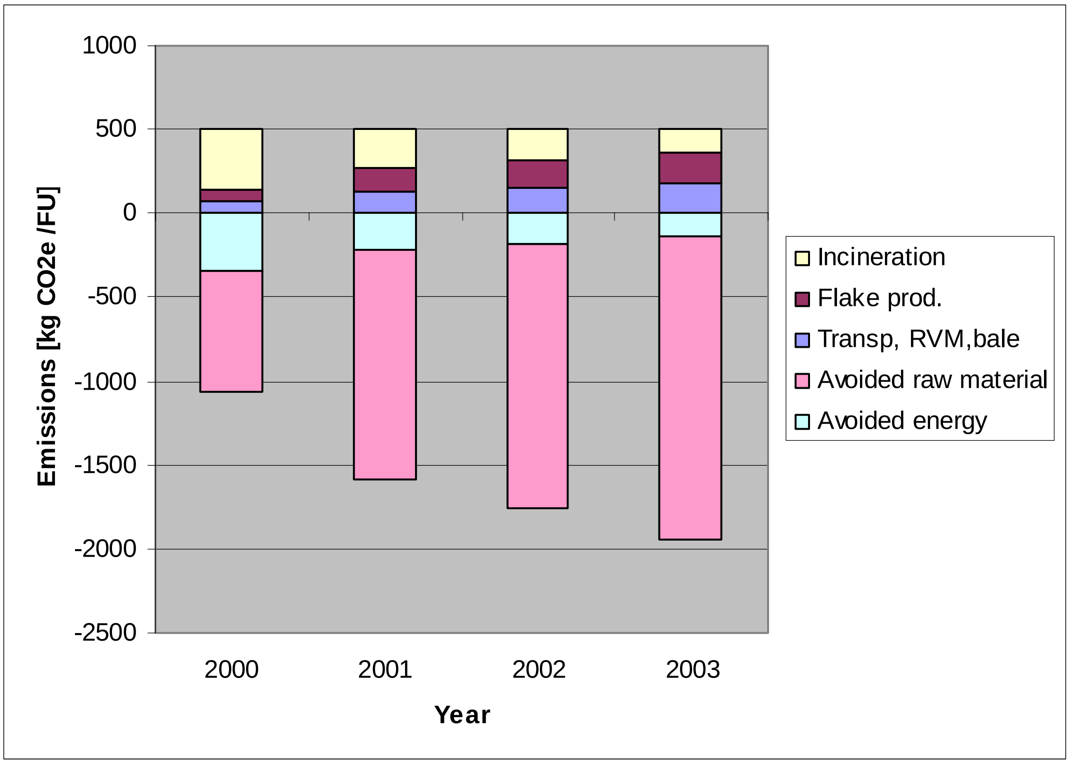

Figure 5.3: Emissions and avoided emissions of GHG 2000-2003 [kg CO_2e /FU]

Finally, it should be mentioned that in the calculation of net GHG emissions, it was assumed that the quality of the PET flakes produced from the PET bottles in the Resirk/PET system was constant in the 2000 to 2003 period. In the net cost section above, I mentioned that the quality of the PET bale, to a large extent decided by the design- and material choices of the PET bottles to enter the Resirk/PET system, and degree of sorting, influenced on the costs of producing the PET flakes. This is also the case for the environmental efficiency; a great variety of bottles in terms of for example colour will reduce the environmental benefits of recycling as coloured bottles are not applicable for the highest quality of recycling. Moreover, it is not always possible or feasible to do a perfect sorting of incoming bales to make a 100 % clean flake available for high quality recycling, especially not in the case where the quality of the bale is poor. As mentioned above neither a detailed analysis of the quality of the bales delivered, the quality of the flake delivered, nor the degree of high quality recycling versus lower quality recycling, is captured in this study.

5.1.4 Eco-efficiency

After having calculated the economic- and environmental performance for PET bottles in the Resirk/PET system separately, it is time to combine them to see how the eco-efficiency has changed during the 2000-2003 period.

In Chapters 2 and 4 we saw that the eco-efficiency can both be expressed as stand alone indicators in an eco-efficiency portfolio diagram, or as a ratio defined by the equation. The eco-efficiency for waste management is given in Section 4.2.4 as:

$$Eco\text{-}efficiency \equiv \frac{Environmental\ influence}{Cost} \equiv -\frac{Net\ GHG\ emissions}{Net\ cost} = -\frac{CO2e/FU}{€/FU} = -\left[\frac{CO2e}{€}\right]$$

Increasing ratio means increased eco-efficiency. This equation is valid for net GHG emissions < 0 and net cost > 0.

In Table 5.8 below eco-efficiency of reclaiming, incineration and landfill of 1000 kg PET bottles in the Resirk/PET system is quantified as the ratio of GHG emissions and net cost. This eco-efficiency expresses how many kg CO_2e that can be saved per Euro spent. In 2002, for example, 0.467 kg CO_2e was saved per Euro spent on waste management of the used PET bottles. Another way to illustrate the eco-efficiency of recycling PET bottles is to set a monetary value of €8.60 per tonne CO_2e[12]. By doing this we can see from Table 5.8 that eco-efficiency has increased from 0.001208 in 2000 to 0.004498 in 2003. As we can see the eco-efficiency has increased every year and almost doubled from 2000 to 2001 and from 2001 to 2003. However, it is worth mentioning that the improvement from 2002 to 2003 was rather small.

Year	Net cost [€/FU]	Net GHG-emiss. [kg CO_2e/FU]	Eco-efficiency [kg CO_2e/€]	Eco-efficiency
2000	4003	- 562	0.1405	0.001208
2001	4062	- 1080	0.2660	0.002288
2002	2683	- 1253	0.4672	0.004018
2003	2758	- 1442	0.5230	0.004498

Table 5.8: Eco-efficiency of the Resirk/PET system 2000-2003

Figure 5.4 shows the eco-efficiency in a portfolio diagram and illustrates, by help of the trend-line found by linear regression, that the eco-efficiency has improved every year, even though the net costs increased slightly from 2000 to 2001 and from 2002 to 2003. The most significant eco-efficiency increase occurred from 2002 to 2003.

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[12] This is the current price (as of 15 December 2004) in the EU's emission trading system for greenhouse gases.

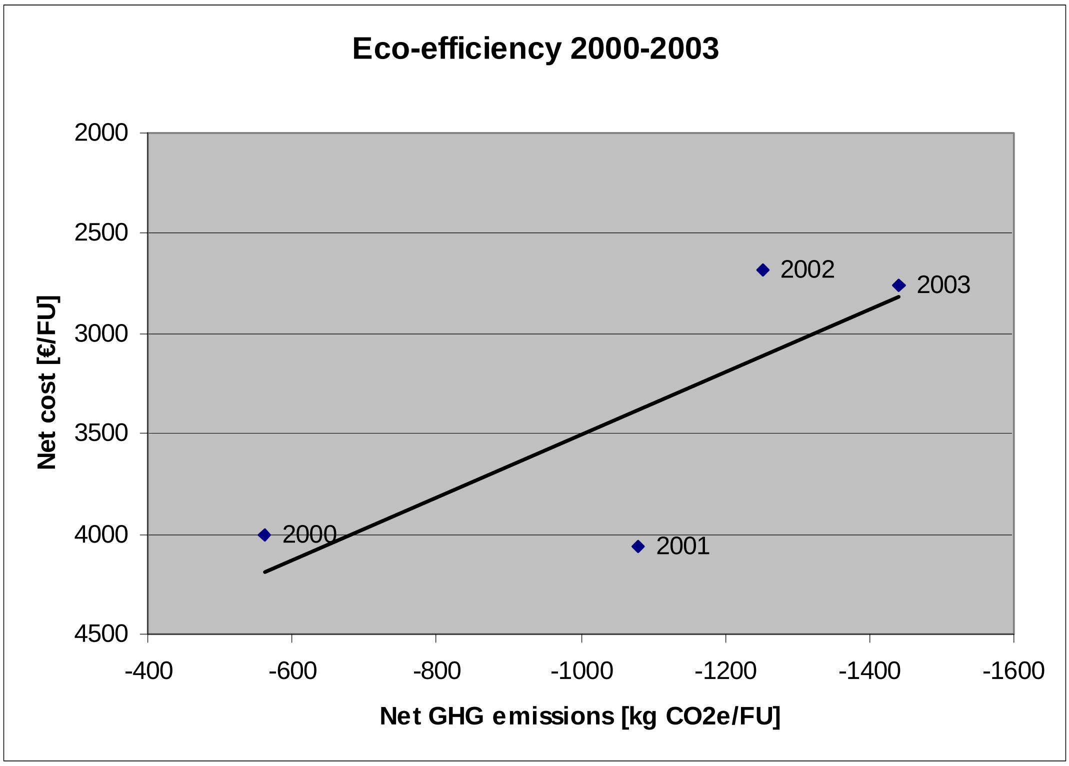

Figure 5.4: Eco-efficiency for waste management of PET bottles in the Resirk/PET system 2000-2003

5.1.5 Comparison with other waste management systems

Before summing up the parameters that have contributed most to the eco-efficiency improvements, I will make a brief comparison between the eco-efficiency of the Resirk/PET deposit system and alternative systems. First I will look at the average recycling rate and reclaiming cost for PET bottles in Europe, before I have a look at the same indicators for the national system for other plastic packaging in Norway.

PET recycling in Europe

In March 2003 the consultancies RDC-Environment and Pira International finalised their study on "Evaluation of costs and benefits for the achievement of reuse and recycling targets for the different packaging materials in the frame of the packaging and packaging waste directive 94/62/EC" (RDC-Environment & Pira International 2003). In this study, which was an important input to the revised EU packaging and packaging waste directive 2004/12/EC, it was found that the average recycling rate of the Member States in EU15[13]

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[13] Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, and United Kingdom

in 2001 was 18 % (PCI July 2002). In comparison, the recycling in the Resirk/PET system was 72 % in 2003.

Table 5.8 and Table 5.9 give the net cost of reclaiming 1 tonne of PET bottles in European areas with high population density and in areas with low population density, via separate kerbside collection and bringing igloo solutions, respectively. Only costs of reclaiming used PET bottles are included, costs for those bottles going to incineration and landfiling is not part of this calculation.

	Transport costs from kerbside	Sorting and baling costs	Transport costs from sorting	Reprocessing costs	Revenues re-processed material	Net cost
High population area	255	474	46	332	-540	**566**
Low population density	306	474	46	332	-540	**618**

Table 5.9: Net cost of reclaiming PET bottles via kerbside collection [€/tonne]

	Transport costs from igloo	Sorting and baling costs	Transport costs from sorting	Reprocessing costs	Revenues re-processed material	Net cost
High population area	196	474	46	332	-540	**508**
Low population density	242	474	46	332	-540	**553**

Table 5.10: Net cost of reclaiming PET bottles via bringing igloo solution [€/tonne]

As we can see from the tables above, the net costs[14] vary from 508 €/tonne reclaimed PET to 618 €/tonne reclaimed PET, depending on collection type and population density. The costs for collection, sorting and baling vary from 670 €/tonne PET bales[15] to 780 €/tonne PET bales. In contrast, the costs per tonne reclaimed PET in the Resirk/PET system in 2003 were 2691 €/tonne[16], whereas the costs for collection, sorting and baling were 2937 €/tonne[17]. Hence, the net cost of reclaiming 1 tonne of PET in the Resirk/PET system is 4 to 5 times higher than the average net cost of achieving the same in Europe. The main reason for the difference is the high cost of the following elements of the

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[14] Correspond to "Net cost" in Section 5.1.2

[15] Correspond to "Bale cost" in Section 5.1.2. Found by adding 196 €/tonne for transport and 474 €/tonne for sorting and baling, see table 5.9

[16] This net cost is calculated by adding bale cost, flake cost, and avoided cost in 2003, see table 5.6 in 5.1.2. Hence, costs of fractions going to incineration and landfilling are not included.

[17] Bale cost 2003 in table 5.6 in 5.1.2

deposit system: information to consumers, investment and operation of reverse vending machine, and transport of returned bottles to sorting.

Reclaiming of other plastic packaging types in Norway

According to Røine (2005) the average cost of collecting (through kerbside or bringing solution), sorting and reclaiming of various types of used plastic packaging in the national Norwegian Plastretur system[18] in 2003 was 607 €/tonne reclaimed material. Avoided costs are not included in this calculation. Costs of the plastic fractions going to incineration or landfill are not a part of this calculation. The costs per tonne reclaimed PET in the Resirk/PET system in 2003 were 3297 €/tonne[19], i.e. more than 5 times higher than in the Plastretur system. However, it must be mentioned that the recycling rate in the Plastretur system was 21 %, while the Resirk/PET system reached 72 % recycling in 2003. Hence, the environmental performance of the Resirk/PET system is most likely far better than if the PET bottle should have been treated in the Plastretur system. Differences in costs of information to consumers, investment and operation of reverse vending machine and transport of returned bottles to sorting are the probably the main reasons for the large difference in overall costs between the two national systems.

Is it worth it?

Even though substantially higher recycling rates is acquired in the Resirk/PET system compared to the European systems based on kerbside and bringing igloos, and compared to the Norwegian system for other plastic packaging, it can be questioned whether the high cost of the Resirk/PET system can be justified. If the PET bottles in this system would instead be going through the Plastretur system, it is likely a fair estimation to say that the recycling rate and the cost to manage of these bottles would not had differed too much compared to the (average) recycling rate and cost for other plastic packaging in Norway, i.e. 21 % and 607 €/tonne per tonne reclaimed material. Hence, if putting the PET bottles in the Resirk/PET system into the Plastretur system, 2690 € per tonne reclaimed PET would have been saved, at the same time as around 1 tonne[20] more CO_2e pert tonne reclaimed would have been released. In other words, the cost of reducing one tonne CO_2e in the Resirk/PET instead of the Plastretur system is 2690 €, which is a lot compared to the 8 €/tonne price in the European emission trading system for greenhouse gases. Even though other (economic) advantages of recycling such as avoidance of litter, avoidance of use of landfill, and avoidance of other emissions from incineration and alternative production of PET is not included in this calculation, it can be discussed whether the Resirk/PET system can be justified under current conditions. However, potential future changes, such as significantly higher volume of PET bottles in the system, may lower the cost substantially and in this way make it more competitive. Hence, it cannot be concluded from this study that deposit system as such is a cost ineffective way of organizing recycling of PET bottles.

For suggestion on how to improve the eco-efficiency of the system, see Section 7.2.1.

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[18] For more information about the system, see www.plastretur.no

[19] This cost is calculated by adding bale cost and flake cost in 2003, see table 5.6 in 5.1.2

[20] Estimate based on the difference between Net (avoided) CO_2e emissions in 2003 and 2000, see table 5.7

5.1.6 Volume and return rate most contributing parameters to eco-efficiency changes

After having gone through the costs and the greenhouse gas emissions of waste management of used PET bottles, it is time to sum up the main findings and most important contributions to eco-efficiency. The eco-efficiency analysis has revealed that:

- The eco-efficiency has improved every year from 2000 to 2003. An upper limit may however, be nearby unless a substantial increase in volume of PET bottles to participate in the system will appear
- Increased volume of PET bottles included in the Resirk/PET system gives increased eco-efficiency due to increased degree of economy of scale effects.
- Increased return rate, and hence increased recycling rate, at least up to 75 % gives improved eco-efficiency.
- The environmental influence, given as net greenhouse gas (GHG) emissions, has improved every year due to increased return rates.
- The economic influence, given as net cost, was reduced considerably from 2000/2001 to 2002/2003 due to higher volume of bottles and improved return rate. However, the net cost was higher in 2003 than in 2002
- Replacement of alternative use of virgin PET when recycling was by far the most important contributor to the net GHG emission indicator. Incineration had the largest opposite effect.
- For all years, net cost was highly related to the costs of making PET bale. The costs of reclaiming, and avoided costs due to recycling and replacement of alternative material had also some impact on the overall cost. The costs of incineration and of landfill contributed less.
- Due to the great variety of the PET bottles in terms of colours, closures and labels in the Resirk/PET system, the design and material specification of the bottles, the PET spec, is an important contributor to the eco-efficiency of the system. This spec is important for the return rate, the systems ability of high quality recycling, sorting costs, as well as money spent on information.

From this we can conclude that the improvement of eco-efficiency from 2000-2003 can mainly be explained by two parameters; increased volume and increased return rate. In the next section, the interactive resource development approach will be applied to examine in what ways the development of the PET bottles that participate in the Resirk/PET system have contributed to shape these parameters.

5.2 Interactive resource development of PET bottles

In the previous section, the eco-efficiency for waste management of PET bottles in the Resirk/PET system in the years 2000 to 2003 was quantified. Volume of participating bottles and return rate was found to be main influencing parameters to the improvement of eco-efficiency during the period. However, in this eco-efficiency analysis it is not possible to understand the background or reason for the improvement of these parameters. In this chapter I will look deeper into which factors that shape and explain the changes of volume and return rate by applying the framework of interactive resource development, which was presented in chapter 3. We will see that Imsdal, chosen because it is the largest bottle fraction in the Resirk/PET system, was influenced by, and influenced on, surrounding resource elements during the time period studied. Moreover we will see that these changes also had consequences for the volume and return rate of Imsdal, and hence the system's eco-efficiency. A particular emphasis will be given to the story of a white spirit sabotage on Imsdal, which occurred in August 2002 when a couple of Imsdal bottles was found to contain white spirit instead of non-carbonated water.

5.2.1 The Imsdal sabotage: Influence on the adapted resources of Imsdal and Ringnes

In this section we will see how the product Imsdal and the producer and owner of Imsdal, the business unit Ringnes, both described in Chapter 4.3.1, through interaction between actors involved, developed and became increasingly adapted in the period from 1994 and ahead. This adaptation resulted in the building of a brand, the Imsdal brand. However, as we will see, the *changing force* of the sabotage in August 2002 led to rapid changes of Imsdal and Ringnes.

Increased adaptation through brand building

<u>Brand building through telling a story</u>

In contrast to many other nationalities, Norwegians are used to drinking tap water gathered from the "pure Norwegian nature". All Norwegians have for a long time had free access to clean water at home. Seen from such a perspective it must have been a ridiculous idea to launch Imsdal in 1994. Why should Norwegians pay for Imsdal when they got clean water in the kitchen for free? One important reason for this strategy was probably tests taken of Norwegian water which revealed that the drinking water in many parts of the country contained humus and other impurities (Flaten 1998). This information may have influenced Ringnes to label Imsdal as "the source to a purer life", and if looking at the sales figures above, it may be that they succeeded to convince the consumer to a steadily increasing degree from 1994 and onwards. It must be noted, though, that 12 million liters sold of the major bottled mineral water in Norway in 2001, only represents an average annual consume of less than 3 liters mineral water per Norwegian inhabitant[21]. Nevertheless, again according to self-confident Ringnes, they “taught Norwegians how to buy and drink water from bottles”. In 1996 Ringnes made the vision that “One day we would like to see a young girl with an Imsdal bottle in her hands walking down Karl Johans gate (the main street of Oslo)”. A couple of years after it seemed like the dream had come true. More and more, especially young people, started to drink Imsdal at the expense of tap water and soda/carbonated drinks. By telling the story about the “pure underground source in Imsdalen”, Ringnes apparently succeeded to make Imsdal into a brand.

Brand building through packaging design

From 1994 to 2000 Imsdal was mainly available on refillable 0.5 and 1.5 liters PET bottles. These were so-called standard refillable bottles, which denoted that bottles were used for several types of beverages tapped at various producers. Hence, I would argue that it is fair to say that Ringnes until 2000 focused on building the Imsdal brand solely through the beverages, not the packaging. There were no bottles which really reflected the Imsdal brand, even though the label, of course, showed that the bottles contained Imsdal. In June 2000 Ringnes decided to launch Imsdal in a 0.6 liter one-way so-called sport bottle in addition to the refillable 0.5 and 1.5 liters standard bottles. The 0.6 liter bottle differed from the other bottles in three ways. It had:

- A light blue bottle colour which “should remind the consumer about the coolness and freshness of the source water”.
- A so-called sports cap which made it easy and quick to open and close the bottle.
- A one way PET material[22] which made the bottle light and easier to carry and to squeeze.

The label was, however, not changed. It got the same blue paper label as the refillable standardised 0.5 and 1.5 liters bottles[23], which remained unchanged.

Ringnes had developed an Imsdal sport and leisure bottle. Very soon this bottle gained popularity among young people, people “on the run”, and people doing sports. However, due to the handy sports cap, many Norwegians started to use the bottle as a refillable bottle. When they had finished their Imsdal water, they refilled, over and over again, the bottle with tap water. It almost seemed like the nice bottle (with tap water) had become the new brand, not the Imsdal water. Had Ringnes failed? Probably not. If we look at the sale figures[24], in Figure 5.5 below we can see that the sales of Imsdal increased from 9.5

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[21] In comparison the mineral water consumption in Italy is around 140 litres per inhabitant per year (REF)

[22] One way PET is to an increasing degree used as beverage packaging because it gives a lot of freedom in choosing desired design. The refillable PET bottles are thicker and harder than the one way PET bottles.

[23] Paper labels are suitable from a recycling point of view. Ironically, seen from a recycling/environmental point of view, due to the nice and useful sports cap the bottles are used as refillable bottle leading to a lower return rate of these bottles than it otherwise would have had. However, since the bottles often are used over and over again by the consumer before being returned to the shop, the paper label sometimes is dismissed. If this happens, it is no longer possible to deposit the bottles since the bar code, which is the basis for recognition in reverse vending machines and petimeters, is removed

[24] Ringnes will not state the sale figures for each of the bottles types.

million liters in 2000 (the 0.6 liter appeared in June 2000) to 12 million liters in 2001. This 20 % increase has in fact been the highest increase in sales from one year to the next. So even though many consumers used the Imsdal sports bottle for tap water, the introduction of the 0.6 liter contributed to strengthen sales and the Imsdal brand.

Imsdal and Ringnes became more and more adapted

The interface between the business unit Ringnes and the product Imsdal was created and shaped through continuous adaptation between the two resource elements, and this adaptation resulted in changes of the resources connected. Imsdal and Ringnes influenced each other and changed while becoming (more and more) adapted from 1994 and ahead. The adaptation between Ringnes and Imsdal in the period 1994 to the beginning of August 2002, contained brand building and human and technological investment processes, and lead to changes of the two resources. There seemed to have been a stable interface between Ringnes and Imsdal in the sense that the two resources were more and more adapted as the time went on. Ringnes succeeded, through storytelling and new packaging, to build the Imsdal brand to an increasing degree in this period. In that sense we could say that there was adaptation between the brand builder, Ringnes, and the brand, Imsdal. Ringnes influenced on the product through this adaptation. However, I would also argue that this adaptation also led to influence the other way around since the product (and brand) of Imsdal "forced" Ringnes to invest in human knowledge and technology to maintain and improve the Imsdal brand. Today there are for example two spring water outlet from the source, the second one was prepared in 2000 to increase the production capacity. Other larger investments were carried out in 1999 when a new tapping and packing machine was installed, and in 1998 when a robot packing machine was bought. To sum up, we have witnessed an interactive development and change of Imsdal as a product/brand and Ringnes as a business unit. Figure 5.5 illustrates how adaptation implied that the two resource elements reciprocally influenced on each other.

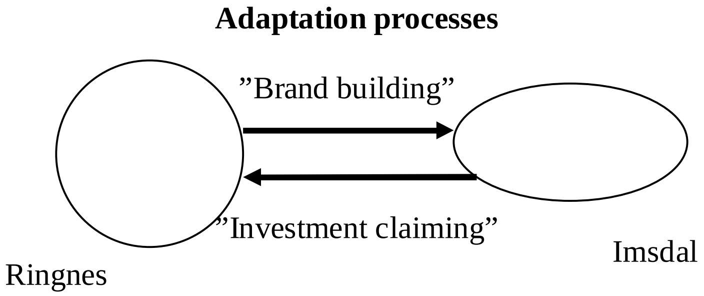

Figure 5.5: Interaction marked by "brand building" and "investment claiming" between the resources Ringnes and Imsdal

Increased sales

In 5.1 we saw that increasing volume of participating bottles in the Resirk/PET system was a parameter that contributed to the system's increased eco-efficiency. To what extent contributed Imsdal to the volume of participating bottles in the Resirk/PET system?

As Figure 5.6 below illustrates the sale of Imsdal increased every year from 1994 to 2001 before it dropped in 2002 due to the white spirit sabotage in August 2002. The total sales of all bottle types of Imsdal bottles in Norway increased from around 2 milion liters in 1994 to almost 12 million liters in 2001. In 2002, the sales decreased to approximately 11 million liters. However, it was estimated a volume of around 13 million liters before the sabotage occurred in 2002. The sale of the only Imsdal bottle that was included in the Resirk/PET system until October 2002, the 0.6 l sports bottle, increased by 250 % from 2001 to 2002. Without the sabotage, the sales of 0.6 l Imsdal would probably been more than tripled from 2001 to 2002. For the Resirk/PET system as a whole the volume of bottles was doubled from 22.1 million in 2001 to 44.4 million in 2002. Hence, I would argue that increased sale of 0.6 l Imsdal, which contributed to 8 % of the total volume of bottles in the Resirk/PET system in 2001 and 10 % in 2002, contributed significantly and increasingly to the overall volume of bottles and hence the system's eco-efficiency in those two years.

From what we have seen here I would claim that the increased adaptation between the business unit Ringnes and product Imsdal resulted in:

- Development and inclusion of Imsdal 0.6 l bottles in the Resirk/PET system.
- Increased sale of Imsdal 0.6 l, and hence positive impact on volume and eco-efficiency of the Resirk/PET system.

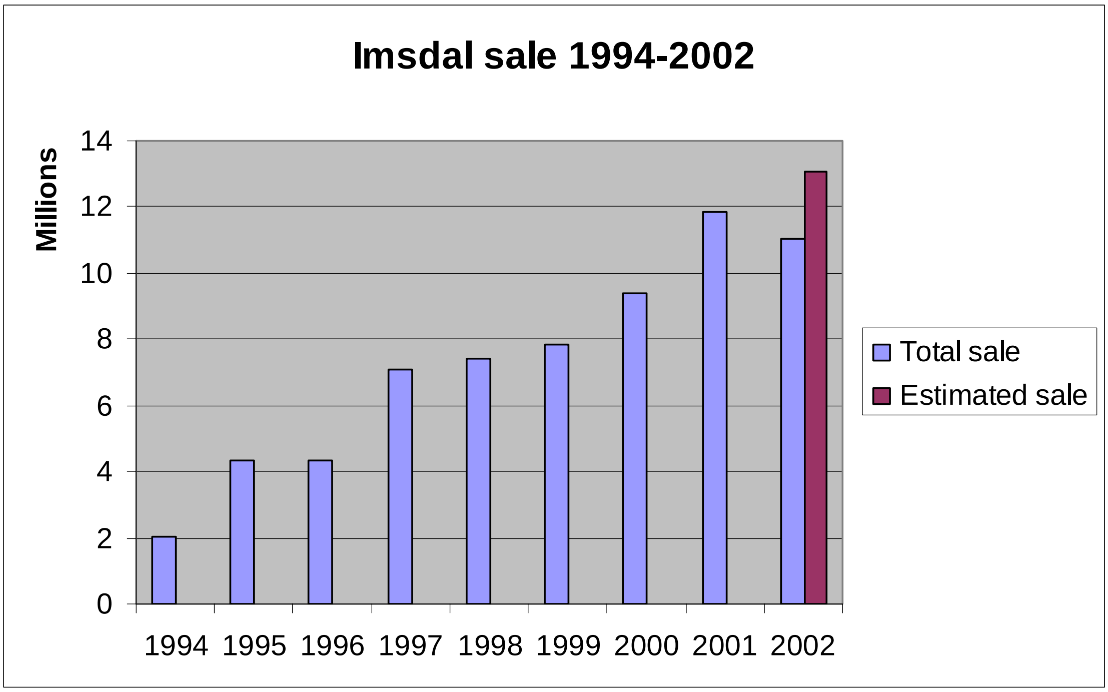

Figure 5.6: Sale of Imsdal in Norway 1994 – 2002 [Million litres]

Increased return rates

As found in 5.1 the increased return rate of bottles in the Resirk/PET system contributed significantly to the increased eco-efficiency of the system.

The return rate of Imsdal in the Resirk/PET system increased with 20 % from 2001 to 2002. This is approximately the same growth as for the average return rate of all bottles in the system, which increased from 56.3 % to 65.2 %. The increased return rate can probably be explained by increased awareness of deposit on PET bottles. However, it is worth to note that the average return rate for bottles in the Resirk/PET system is higher than for the Imsdal bottles. This may be explained by the design of the Imsdal bottles. It could be that the design of the 0.6 l Imsdal bottle did not encourage consumers to return bottles. I have already mentioned that some bottles were used as a refillable bottle and hence not returned. Another reason could be that Imsdal differed from the other bottles since Imsdal had a blue colour, while most of the other bottle types were clear. Hence, it may be that the consumers did not think about Imsdal bottles as deposit bottles (to be returned) in the same way as other bottles. However, in order to see whether such a theory really make sense, further research is needed. To sum up, I would argue that it is difficult to find a clear connection between the interactive development of the Imsdal and this bottle type's increased return rate, and hence influence on the return rate and the eco-efficiency of the Resirk/PET system. Increased return rate, both for Imsdal as well as for the system as a whole, can probably rather be explained by factors involving resource interfaces between the consumer and other resource elements.

Adaptation through interaction marked by rescuing, and rebuilding, of a brand

Above we have seen that increased adaptation between Imsdal and Ringnes contributed to higher sales of Imsdal. The adaptation occurred through brand building and investment claiming. In the next section we will see that the changing force of the white spirit sabotage resulted in a situation where the adaptation was no longer based on *building* a brand, but rather on how to invest in human and technological resources to *save and re-build* a brand.

The white spirit sabotage

The first mysterious findings made done in a shop in Oslo on the 2nd of August 2002. Tests revealed that two bottles contained white spirit. This resulted in a comprehensive check of the Imsdal production facility and the production routines, but nothing wrong was found. Ringnes thus handled this as a one-time incident. But the problems were not over. 17 days later another two bottles containing white spirit were found in Moss, about 100 km south of Oslo. Chemical analysis revealed that this was the same white spirit as used in the bottles found in Oslo. The sabotage was, as one interviewee described it, the "first incident of foodstuff terror and therefore Ringnes' credibility was at stake" A new era of "food safety had to emerge", the informant continued. On the 22nd of August Ringnes withdrew Imsdal from the market. It stayed out of the market until the 7th of October 2002 when Imsdal was re-launched. In the following we will have a look on how the adaptation between Imsdal and Ringnes both within this period and also afterwards was marked by human- and technical investments to re-build the Imsdal brand.

<u>Rescuing and rebuilding the brand</u>

Three days before Imsdal was removed from the market, an emergency action group was established by Ringnes. This group consisted of 15-20 people from the Ringnes management group, PR advisers and people responsible for the Imsdal product. The group's mandate was to ensure that Imsdal would be back on the shelves within one month, and in parallel they had to organize the temporarily withdrawal of the product. The premise for the re-launch was that the "new" Imsdal had to be:

1. Secure
2. Visible
3. Permanently back in the market

As we saw in the previous section, the first eight years of Imsdal were marked by adaptation to build the brand. In the six weeks when the bottles stayed out of the market the situation was different. In those weeks the adaptation was marked by re-building trustworthiness and finding technical solution which could save the Imsdal brand and in this way keep the resource elements of Ringnes and Imsdal adapted. This had to be done without compromising the emergency action shown above. The solution the action group came up with was to change the 0.5 liters and 1.5 liter bottles from clear *refillable* PET bottles into the lighter and somehow differently shaped blue *one-way* PET bottles equipped with an extra closure sealing to prevent a similar sabotage. The question was then to find a solution on how to do this within the scheduled time frame of one month. One problem was that the Imsdal product was embedded due to technical investments in production and production facility. Hence, Ringnes had to choose bottle types which were already adapted to the tapping line, and closure sealing equipment which could be adapted and installed on the limited space next to the tapping line. Regarding the establishment of the closure sealing, Ringnes succeeded to find a simple technical solution which only required relatively small investments with only three weeks delivery time, not the usual three months delivery time. As for the bottle, earlier investments turned out to be an opportunity, not a lock-in, to easily find a solution. The reason for this was that Ringnes already exported one-way 0.5 liters and 1.5 liters Imsdal bottles to the Swedish market. That meant that these bottles already were technically adapted to the tapping facility, and equally important, Ringnes already had a business relationship with the bottle suppliers through the purchase of various types of bottles. The production facilities had the equipment to tap on one-way 0.5 l and 1.5 l because these two products were already delivered by the bottle suppliers AB Kulleborn for 0.5 liter bottles and Stenström and Rostiprimpac for the 1.5 liters. These had been Ringnes' suppliers of clear one way 0.5 l and 1.5 l bottles for Imsdal to the Swedish market since 1998 and hence it was easy to arrange a deal. However, since the sales of the *blue* Imsdal 0.6 l sports cap bottle were very high before the sabotage, Ringnes decided to also change the colour of the 0.5 and 1.5 export bottles liters to blue. Good sales figures along with consumer tests carried out before and after the sabotage indicated that the design of the 0.6 liter sports bottle, including the colour, was appreciated among consumers. Ringnes had found a smart solution both from a technical and commercial point of view. In a changing situation like this, there will usually be discussions whether attractive bottle design or bottle adaptation to existing tapping facility should be most emphasized. Designers and marketing people may emphasize nice design, while technicians or production people argue that technical adaptation to the tapping facility is most important. However, this time they all agreed that applying the Swedish bottles was a good solution both from a visual and technical adaptation point of view. A product family of Imsdal in transparent blue one-way PET bottles for the Norwegian market, as well as other markets, was created. Even though the beverage was the same as before, the change of two out of three bottle types and the introduction of a new closure sealing on all tree bottle types made in many ways Imsdal into a modified product.

The lost market share, due to the sabotage, had to be re-gained. The changes presented above should hinder future sabotage and at the same time attract the consumers. However, as we have seen, these initiatives could not been implemented in a flash, even though everything was carried out to re-introduce the product as soon as possible. Other beverages, even though these products also were marked by the sabotage and the fear it created, had taken the position as market leaders while Imsdal were out of the market. However, only a couple of weeks after Imsdal was relaunched they had re-gained their market share.

Observer Executive (2002) made an evaluation as to what extent Ringnes managed to control the media coverage of the white spirit sabotage. Their conclusion was that Ringnes managed to do this by being vigorous and ensuring open communication. They succeeded to turn the sabotage into a question of food and beverage security in general, and hence valid for all brands, not only Ringnes'. The focus on security at the expense despite of short-term income placed Ringnes in a positive light, Observer Executive found.

Increased adaptation

When the sabotage appeared and this changing force was distributed to the interface between Imsdal and Ringnes one should, according to theory of friction presented in 3.4.4, normally expect that this could lead to a de-stabilisation, and at worse case a separation between the business unit Ringnes and product Imsdal. However, I would argue that quite opposite happened; the changes of the two resources as well as the adaptation process increased as illustrated in Figure 5.7. This can for example be seen in the way Ringnes quickly committed themselves by spending a lot of resources to rescue and rebuild the Imsdal brand. It seemed like the brand grew even stronger since it, as a result of the introduced extra closure sealing, became perceived as a safer product among consumers. Besides, by changing all bottles into blue coloured one-way, Ringnes succeeded in making a more uniform Imsdal product family.

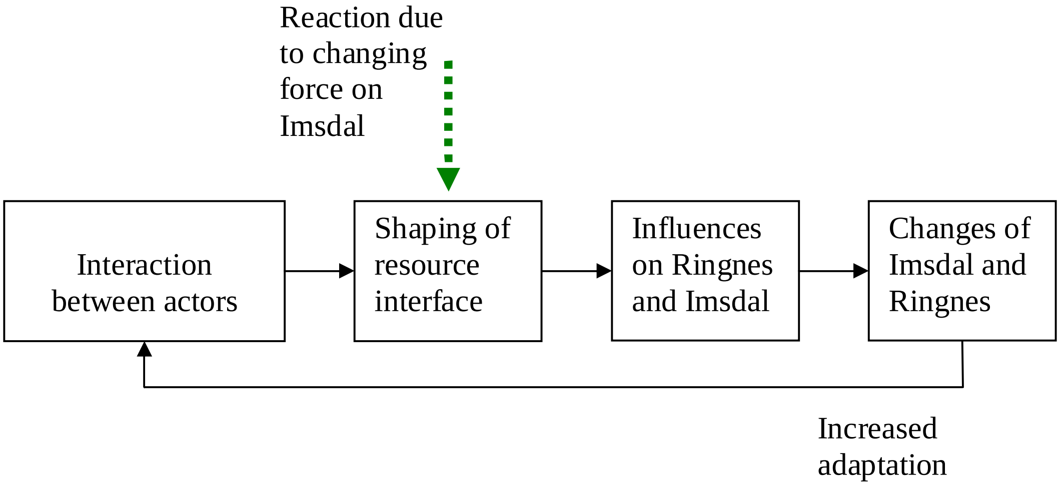

Figure 5.7: Increased adaptation and changes of resources of Ringnes and Imsdal

<u>Increased sale</u>

As mentioned before increased volume of PET bottles in the Resirk/PET system implied increased eco-efficiency of the system.

The introduction of 0.5 liter and 1.5 liter Imsdal bottles in the Resirk/PET system, which was a consequence of the white spirit sabotage and increased adaptation between Imsdal and Ringnes, resulted in a growth of Imsdal bottles in the system. The amount of sold Imsdal bottles in the Resirk/PET system more than doubled from 2002 to 2003. In the same period the volume of participating bottles in the system increased from 44.4 million bottles to 52.7 million. Actually, most of the growth of bottles in Resirk/PET from 2002 to 2003 can be explained by growth of Imsdal bottles. Hence it would be fair to say that the adaptation process of re-building the brand, including the introduction of new Imsdal bottles, made an important contribution to the Resirk/PET system's improved eco-efficiency from 2002-2003. The sabotage was an important reason for the increased adaptation between the product Imsdal and business unit Ringnes.

<u>Slightly improved return rate</u>

Increased return rate of bottles in the Resirk/PET system means increased eco-efficiency.

The average return rate for all three types of Imsdal bottles increased by 30 % from 2002 to 2003. In comparison the return rate for bottles in the Resirk/PET system as a whole increased by 11.5 %. Hence, the return rate of the Imsdal bottles increased relatively more than the average return rate of all bottles in the system. However, I would be slightly cautious to conclude that it was the sabotage and the subsequent interactive development of Imsdal that made the major impact on the increased return rate. However, as the sabotage resulted in introduction of two new Imsdal bottle types, which both quickly acquired high return rates, it may very well be that the interaction and adaptation process of rebuilding the Imsdal brand ensured improved return rate and eco-efficiency in 2003. Possible explanations could be that:

- Introduction of standard deposit look-alike new 0.5 liter and 1.5 liter bottles were quickly perceived as deposit bottle among consumers
- Establishment of a product family of three types of blue coloured Imsdal bottles ensured that consumers to an increasing degree perceived Imsdal as refundable deposit bottles.

5.2.2 The Imsdal sabotage: Influence on PET spec and PET bale

In the previous section we saw that the white spirit sabotage influenced the business unit Ringnes, the focal product of Imsdal, as well as on the volume of Imsdal bottles included in the Resirk/PET system, and, to a certain extent, the return rate of Imsdal bottles. Hence, the sabotage contributed to increased eco-efficiency. Here we will see that the sabotage also influenced the interface of and adaptation between the facility of PET spec and the PET bale product. See Chapter 4.3.3 and 4.3.4 for a description of these two resources and the resource interface between them. However, let us first have a look at how the PET spec and the PET bale were connected before the sabotage occurred.

Introduction of less-recyclable bottles

On the basis of requirement inputs from business units such as a the major RVM supplier, several reclaimers, and producers and importers of beverages, the first design and material specification for PET bottles (the "PET spec") for the Resirk/PET system was developed and published by Norsk Resirk in June 2000. This spec was partly based on experiences from the development and use of the Resirk/PET system's aluminium spec, which was developed in 1998. The PET spec contained the following requirements (see Appendix B for complete spec):

- Physical shape
- Dimensions
- Bar code placement
- Bottle material
- Bottle caps material
- Labels
- Label glue

There were no restrictions on use of coloured bottles in this spec. Basically, requirements with respect to physical shape, dimension and bar code placement should ensure readability in reverse vending machine and petimeters, whereas the other requirements were made to ensure as high quality as possible of the PET bale. However, as we will see below, not all bottles that entered the system were optimal in terms of readability and recyclability.

Even though the spec was made on the basis of input from the major beverage producers and importers, and hence should have taken all important material and design aspects into account, problems with the undesired bottles in the system occurred rather soon after the Resirk/PET system was established. Partly due to the decision on making a not too strict spec, and more importantly, the fact that Norsk Resirk did not know about all emerging bottles when they made the PET spec, undesirable bottles started to enter the system only after a few months. Among several examples, it is worth to mention the following bottles, which all caused problems for reclaimers that received them:

- Bottle with oriented polystyrene label
- Bottle with water solvent not recycling-friendly glue
- Coloured bottles

Only a few months after PET bottles were introduced in the Resirk system, one of the main producers introduced a bottle with a label that covered most of the bottle, and hence made the bottle unsuitable for material detection and consequently high quality re-processing at the reclaimer. However, the main problem with this bottle was not the size of the label, but rather the fact that the label contained oriented polystyrene (O-PS). Reclaimers are well aware of the problem the material may cause problem in the reclaiming process. In recycling guidelines such as the one from the influential PET containers recycling Europe (PETCORE) this type of label is not recommended (Petcore 2005). In Norsk Resirk's first PET spec from June 2000 it was mentioned that the labels should be made of paper, PE, PP/OPP or silk print. It was not clearly specified in the spec, however, that O-PS was not accepted, and as a consequence of this the bottles containing this types of label could relatively easily enter the Resirk/PET system. However, after pressure from Norsk Resirk the O-PS label were removed from the bottles in 2002.

Another case was the bottles containing label glue which was water solvent, as required by the spec, but still unwanted among reclaimers. This bottle type could enter the system because the spec required use of water solvent glue, and did not specify that the glue should be *both* water solvent and acceptable to recycling.

The main problem from a PET bale, and hence recycling point of view, however, was the high fraction of coloured bottles which made a major negative contribution to the recyclability of the bottles. Coloured bottles have a more limited user area than clear bottles, and hence the sales price (which influence on the eco-efficiency of the system), is lower for secondary raw material from coloured bottles than from clear bottles.

The problem of coloured bottles

The table below shows that the amount of coloured bottle among the returned PET bottles increased from 17.3 % in 2001 to 19.3 % in 2002 and. Unfortunately, there is no data for 2000 available.

Year	Fraction of coloured bottles in system	Dominant coloured bottle types
2001	17,3 %	Imsdal 0,6 l (88 %) Dark dog 0,33 l
2002	19,3 %	Imsdal 0,6 l (52 %) Cola light 0,5 l

Table 5.11: Coloured PET bottles in the Resirk system 2001 and 2002

In 2001 there were, as Table 5.10 shows, mainly two products that contributed to the high level of coloured bottles: the 0.33 l yellow opaque Dark Dog, which disappeared in 2002, and, in particular, the transparent blue 0.6 l Imsdal bottle which contributed to 88 % of the coloured bottles fraction. In 2002 Coca Cola's 0.5 l silver coloured bottle appeared, making this bottle equally dominant to Imsdal 0.6 l that year. It is worth to mention that Cola's silver bottle was a campaign bottle that only was in the market for some summer and autumn months in 2002. Still, this single product managed to make a significant impact on the colour content of the bales produced.

What these observations most of all tell us is that a system with small bottle volumes, such as the Resirk/PET system, is very *vulnerable*. In a larger market, single bottle types would not have the potential to influence on the colour fraction of the bales in the same way as Cola Light, Dark Dog and in particular Imsdal did in this period.

To sum up, the empirical material reveals that the problem of undesirable O-PP labels, non-recycling friendly glue and coloured bottles were a problem almost from the day of start-up of the Resirk/PET system. The PET spec seemed not to be able to prevent, from a recycling point of view, undesirable bottles to enter the Resirk/PET system and hence the PET bales. The main reason for this was probably that the spec had remained unchanged since it was introduced in the newly established PET system in June 2000, even though there were discussions already in December 2000 to what extent there should be limitations on for example coloured bottles. The original spec, apparently a rather *heavy* resource since it did not change in accordance with changing surrounded resources, such as the PET bale, could not foresee all type of new bottles, caps, labels and adhesives entering the market.

New Imsdal bottles entered the Resirk/PET system

In 5.2.2 we saw that the white spirit sabotage on some Imsdal bottles resulted in the introduction of a new type 0.5 liter and the 1.5 liter Imsdal bottles, both included in the Resirk/PET system. The sabotage influenced on the adaptation between the Ringnes business unit and the Imsdal product, which also resulted in a change of the Imsdal bottles. This change had positive contribution in terms of increased volume and return rate of Imsdal, and hence improved eco-efficiency of the Resirk/PET system. In this section we will see that the white spirit sabotage also had an influence on the interaction between the facility PET spec and the product PET bale.

On the 17th of October 2002 when the first blue one-way 0.5 and 1.5 liter Imsdal bottles entered the Resirk/PET system, the PET spec facility and the PET bale product was, as we saw above, not very well adapted. The spec had allowed bottles, labels and glue types which were not desirable from a PET bale point of view. Experience also revealed that the quality of the bale could be vulnerable to the material content of single bottle types. Hence, the interface between the spec and bale, was unstable already before the 0.5 liter and 1.5 liter Imsdal bottles entered the stage.

In the eco-efficiency analysis we saw that good bale quality made at lowest possible cost is important to make an eco-efficient PET recycling system. Even though there are guidelines on characteristics for different bales types, such as indication of required size and density, and, to some extent, the material quality, there are no international quality standards for exact required composition of PET bales. The reason is two-fold:

- Difficulties of specifying clear requirements because there are so many different types of bottles in the bale in terms of colour, label, glue etc.
- It is very time- and cost consuming to measure and to control the exact composition of each bale.

However, most reclaimers have developed their own bale specifications which their suppliers should fulfill. These documents usually contain requirements on maximum amount of elements such as cans, other plastics than PET and content of coloured PET bottles. The Danish reclaimer Expladan, which has been the main buyer of PET bales from the Resirk system since start-up in 2000, has developed a bale specification document for Norsk Resirk. This document gives limitations on the content of glass, aluminum cans, coloured bottles and other impurities in the bales.

As mentioned before the content of coloured bottles is one of the factors that contributes most to the price reduction of PET bales and of PET flakes. The reason for that is that coloured material is not as applicable as clear material when it comes to recycling into new high quality products.

No restrictions on introduction of coloured bottles

Even though Ringnes knew that blue coloured bottles were not preferable from a recycling point of view, they decided for other reasons to go for these bottles. The PET spec, which had been unchanged since the introduction of PET bottles in June 2000, did not put any restrictions on use of blue bottles. If Norsk Resirk had managed to change the spec earlier, when they noticed that the number of blue bottles in the system was too high, and, equally important, that the system was vulnerable to popular products entering the system, Ringnes would possibly not have decided to change from clear to blue bottle.

However, the spec seemed to be a fixed resource that was not easy to change in accordance with the bottle market and demand from the reclaimers.

Amount of blue bottles in bale increased

Only a few weeks after re-launch in October 2002 Imsdal was again the dominant non-carbonated mineral water in Norway, and after a couple of months the consumers started to buy Imsdal to the same extent as before the sabotage. This meant that more transparent blue bottles entered the system. Fortunately, from a recycling point of view, the yellow Dark Dog and Coca Cola's silver bottle were withdrawn from the market and only a few of these bottles were returned in the first month of 2003. Still, as we see from Table 5.11, the content of coloured PET bottles became higher than before the sabotage, and moreover, Imsdal were by far the most dominant coloured bottle types.

Year	Fraction of coloured bottles in system	Dominant coloured bottle types
2002	19,3 %	Imsdal 0,6 l (52 %) Cola light 0,5 l
2003	23.3 %	Imsdal 0,5 l, 0.6 l, and 1,5 l (98 %)

Table 5.12: Coloured PET bottles in the Resirk/PET system 2002 and 2003

The reclaimer Expladan who received the PET bales was not overwhelmingly positive about this development. Ringnes' decision to change from clear to blue Imsdal bottles made a significant negative impact on the bale quality. Although other problems such as new bottles with recycling damaging labels and glue continued, it seems like the appearance of the 0.5 liter and 1.5 liter Imsdal were the decisive factor for doing something with the PET spec. The content of coloured bottles was already too high, and Norsk Resirk feared that other large producers or importers, such as the case of Coca Cola and Dark Dog illustrated, also would find it as easy and interesting to introduce coloured bottles. Something had to be done.

New spec appeared

On the 26th of May 2003 Norsk Resirk invited representatives from the producers, importers, retailers, reverse vending machines supplier and the reclaimer to a meeting. A project group for "PET strategy and material spec" was established. At the meeting it was decided to hire someone to collect input from all the actors on how they preferred the PET bottle spec to be. Three months later the group met again to discuss the new spec proposal which had been put together on the basis of the actors's view. This meeting resulted in some small modifications in the proposed spec, and on the 13th of December 2003 the new PET spec was, after some more small modifications, accepted at Norsk Resirk's board meeting. Among the agreed changes was a further limitation on bottle shape, on use of label material and label glue types, and, not at least, limitations on coloured bottles. It was decided that coloured bottles should be charged for an extra administration fee of 0.1-0.15 NOK per bottle. Such a fee constitutes around 10 % of the price producers pay for the bottle, and hence Ringnes had to accept annual extra costs of around 1 million NOK. However, since this fee was calculated on the basis of the reduction of the material value of the bale these bottles caused, Ringnes did not have a problem in accepting the extra costs. Another important aspect of the spec is that it is only valid until “new modifications are required”. Hence, the spec aims to be more closely connected to the task of preventing or reducing new unexpected non-recycling preferably bottles to enter the Resirk/PET system. It should be modified when it is required, not after a certain period of time. In this way the spec and the bale will this time probably remain adapted. The spec will to an increased degree be able to decide the quality of the bale.

It is remarkable how smooth the process of modification of the PET spec appeared to be. Although this modification process resulted in extra costs and limitations for producers’ and importers’ ability to choose bottle types, closures, labels, and label, there were no serious intentions to stop it. A mutual understanding of the importance of reduced sorting costs and increased bale quality was very much present among the actors. The principle of ‘polluter pays’ was agreed upon. One important reason for the ease of changing the spec was undoubtedly the good relationship between the various actors. There are few large actors in the system and many of these have known each other for many years. The relationship between Norsk Resirk and producers and importers should be particularly emphasised. As mentioned earlier these producers and importers were included when the first spec was made in June 2000. A relationship was, however, not only important when it came to the development of the bottle spec. It was similarly important when it came to use of the bottle spec. Producers used the bottle spec as input for bottle design, while importers had to use it to check whether foreign beverage products also could be accepted in the Resirk/PET system. Norsk Resirk used the spec to check whether new bottles should be allowed to enter the system. This acceptance procedure required frequent discussion between representatives from Norsk Resirk and producers/importers and contributed hence to the creation of the relationship.

Increased de-adaptation

The material and design specification for PET bottles in the Resirk/PET system first changed after almost three and a half years after it was introduced. During this period the PET bales changed in terms of increased impurities and content of coloured bottles, and the spec could do less to prevent this, even though ensuring bale quality was an important purpose of the spec. Ideally, the bottle spec should have influenced the PET bale since it determines which bottles to accept and hence the quality of the PET bale. Conversely, the PET bale should have influence on the PET spec because the quality of the PET bale gives feedback to what extent the bottle spec is strict enough. However, the spec did not change even though it “received input” from the changing bale that it should have been modified in order to ensure the quality of the bale. Hence, there seem not to have been much adaptation between the two resource elements during the three and a half years. Figure 5.8 tries to illustrate this phenomenon from the time Imsdal was re-launched and onwards. In October 2002, the PET bottle spec and the first bales produced were not well adapted. In the time after Imsdal was re-launched the lack of interaction continued and the two resource elements became less and less adapted. In contrast to situations where two resource elements change in relation to each other and become more and more adapted, the spec and the bale became less and less adapted due to lack of interaction between involved actors and corresponding changes of the spec. The interface connecting the two resources was destabilised and this destabilisation process resulted in creation of the new spec.

As a result of three and half years lack of interactive development between the bale and spec, as well as the introduction of blue Imsdal bottles, the seemingly fixed facility of a bottle spec had changed to a spec with more limitations. As mentioned above, an important reason for the change was Ringnes' decision to introduce transparent blue 0.5 liters and 1.5 liters Imsdal bottles in the system in October 2002. This resulted in a higher content of coloured material in the PET bales, and, possibly more important, it demonstrated the lack of producer incentives for choosing the more recycling preferably clear bottles. Hence, it can be argued that the changing force of the sabotage resulted in a shift towards more blue Imsdal bottles which contributed to the modification of the spec. The changing force of the sabotage resulted in a reaction that produced a destabilising effect on the already de-stable interface between bale and the spec. The tensions the changing force created in this interface resulted in the spec change in December 2003, 16 months after the sabotage occurred. Hence, the empirical material reveals that the changing force on Imsdal had effect which was distributed to the distant bale - spec interface where it had an effect a rather long time after it struck Imsdal. As figure 5.8 illustrates, the reaction from the changing force contributed to increase the de-adaptation process between the bale and the spec.

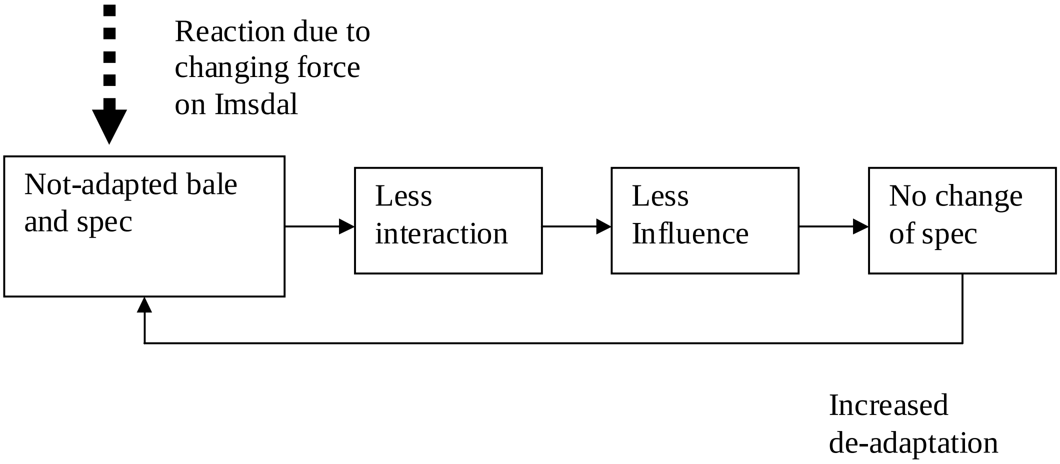

Figure 5.8: Increased de-adaptation between PET spec and PET bale October 2002 to December 2003

Figure 5.9 shows how Norsk Resirk's aims to establish a new spec that is, and maintains to be, by changing it when appropriate, well adapted to the bale.

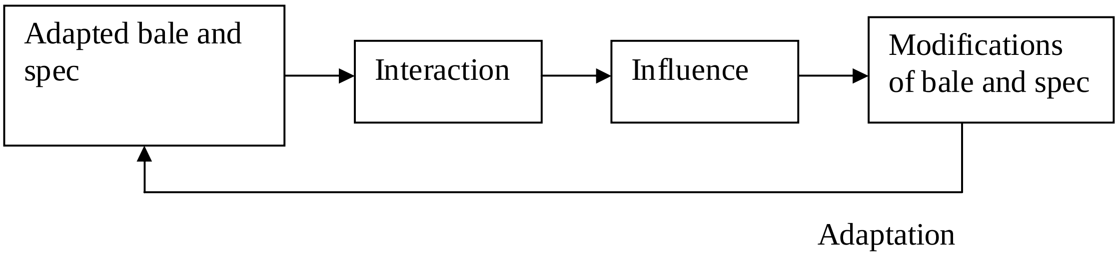

Figure 5.9: Desired situation after new PET spec established

5.2.3 Summary

This analysis of Imsdal and interrelated resources has shown that changes are difficult to predict. The more or less serious attempt of sabotage carried out by filling four Imsdal bottles with white spirit in two different shops resulted in unpredictable effects. By using the friction perspective within the framework of interactive resource development I have found that:

- The sabotage resulted in a substantial growth of Imsdal bottles in the Resirk/PET system, and possibly also to increased return rate of these bottles. Hence, the sabotage contributed to increased eco-efficiency in the Resirk system.
- Another result of the sabotage was the increased fraction of coloured bottles in the Resirk/PET system. This had negative impacts on the eco-efficiency of the Resirk/PET system because it contributed to increased sorting costs at the reclaimer and reduced value of the PET flakes, the final product of the Resirk/PET system. I have no data on how much eco-efficiency was reduced, however it is most likely that it was more than outweighed by the positive contribution from increased volume and improved return rate due to the sabotage.
- The changing force of sabotage produced, through friction, a reaction that lead to changes in Imsdal's resource structure. I have identified changes of the product Imsdal, the business unit Ringnes, the product PET bale and the facility PET material and design specification, see Figure 5.10 below. It is very likely that changes in other resources can be revealed as well.

- A changing force can be *distributed* and create *tensions* and thereafter changes in interfaces and resources both right after and a *long time* after it struck. This is well demonstrated in the case of Imsdal resource which changed rather quickly, and in the case of the PET spec resource where sabotage contributed to changes 16 months after the sabotage.
- Changes can occur on resources which seem to be adapted (Imsdal-Ringnes) as well as less adapted (PET bale - PET spec), i.e. in both stable and unstable interfaces
- The changing force strengthened and accelerated the ongoing processes of adaptation between Ringnes and Imsdal and de-adaptation between bale and spec.
- Lack of interaction between involved actors resulted in de-adaptation between the PET spec and the PET bale.

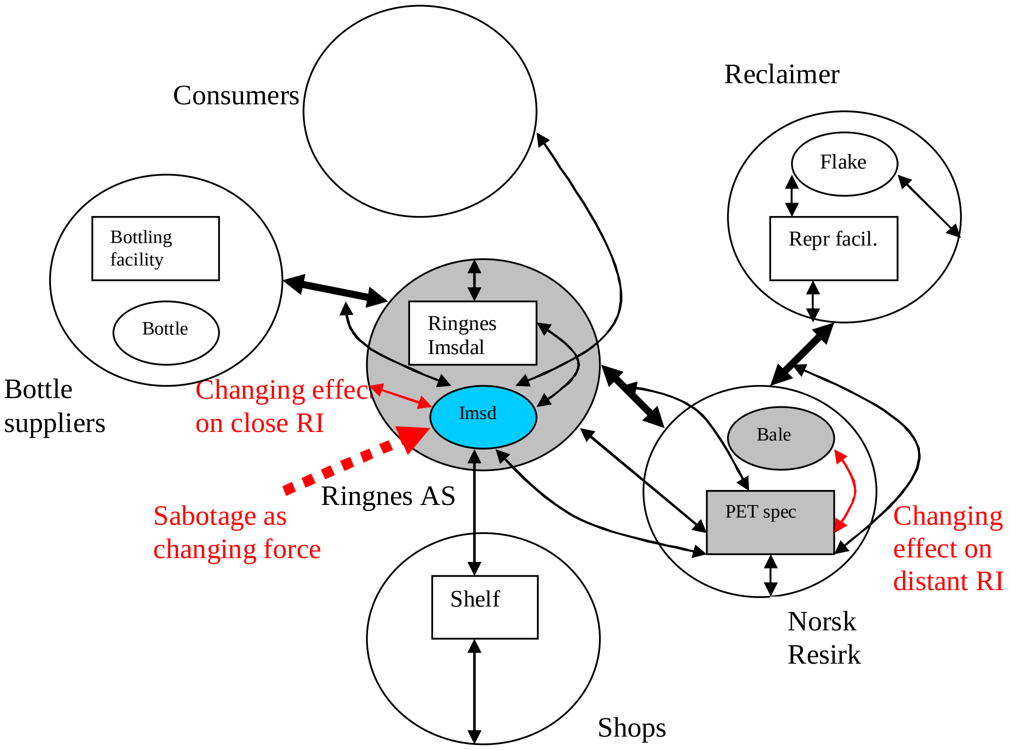

Figure 5.10: Imsdal's resource structure, and changing effects on close and a more distant resource interface (RI) due to sabotage on the focal resource Imsdal

6. Uncertainty and sensitivity

In chapter 5 I found that the eco-efficiency in the Resirk/PET system increased in the 2000-2003 period, and, furthermore that the volume of participating PET bottles and return rate of these bottles were the most important parameters for the change of eco-efficiency. Moreover, I found that the white spirit sabotage on Imsdal bottles in August 2002 had an important influence on the development of the Imsdal bottles and interrelated resources. We also saw that the sabotage influenced the volume and, possibly, return rate of the Imsdal bottles in the Resirk/PET system and hence the eco-efficiency of the Resirk/PET system. In this chapter I will look at the validity and uncertainty of these findings.

6.1. Uncertainty of eco-efficiency results

6.1.1. Material flow

The material flow of the Resirk/PET system is given in section 5.1.1. As the number of bottles sold and returned is automatically registered, the uncertainty of the amount of sold and returned bottles in the Resirk/PET system, given in tonnes, is restricted to the weight of the bottles. This assumed weight changed from 35 g in 2000 to 2001 to 35.7 g in 2002 and 2003. The calculated weight is based on actual bottle mix of sold and returned bottles, and hence the uncertainty is considered to be relatively low. However, it should be mentioned that a change in actual bottle weight of for example 5 % will have a similar impact on the net cost and net GHG emissions.

The calculated recycling rate is based on an assumed material loss of 4 % from used bottles to produced PET flake. This is a relatively low estimate. However, a slightly higher actual material loss will not change the net cost substantially.

The assumption that 67 % of the PET bottles in the Resirk/PET system that were not returned for recycling ended up at landfill, whereas 33 % was incinerated with energy recovery, is partly uncertain as this is based on the average destiny of all household wastes in Norway. However, as Table 6.1 below shows, changed assumption on distribution between landfill and incineration will only have minor impact on net GHG emissions and net cost calculated in 2001. An assumption of 100 % of the PET bottles going to incineration with energy recovery will have a slight influence on the net cost (the net cost of such a scenario in 2001 would have been 92 € lower). However, it is not very likely that all non-returned bottles were sent to incineration in 2001.

	2001	50 % / 50 %	100 % inciner.	100 % landfill
Change net cost [€/FU]	0	- 3	-92	+20
Change net GHG [CO_2e/FU]	0	+2	+5	-6

Table 6.1: Sensitivity analysis PET bottles to landfill and incineration in 2001

6.1.2. Net cost

As we saw in chapter 5.1 the net cost of recycling, incineration, and landfill of 1000 kg PET decreased from 2000 to 2003. Moreover, we saw that production of PET bales from used PET bottles was the cost element that contributed, by far the most, to the overall net cost. In this section I will have a brief look at the uncertainty of most of the cost elements to check the uncertainty of the net cost calculated. The net cost, calculated in chapter 5.1, was highest in 2001 (4062 €/functional unit (FU)) and lowest in 2002 (2683 €/FU]. The net cost in 2001 was 1.5 % (59 €/FU] higher than in 2000, whereas the net cost in 2003 was 3 % (85 €/FU] higher than in 2002.

PET bale costs
The cost of transferring used PET bottles into PET bales contributes by far the most to the net cost of the defined Resirk/PET system, and these costs should hence be thoroughly studied. However, due to the fact that data are gathered from Norsk Resirk's annual account balance and modified, and moreover that the same allocation methods for calculation of these cost at Norsk Resirk is applied during the whole 2000-2003 period, I consider the uncertainty to be very low.

PET flake costs
The cost of producing and delivering PET flakes from delivered PET bales, calculated on the basis of Norsk Resirk's PET bale prices, average European PET flake prices and 10 % reclaimer margin, is uncertain. The bale prices are based on information from Norsk Resirk's annual accounts and should be fairly reliable. It should also be reasonable to assume that Expladan , the Danish reclaimer that the Resirk/PET system supplies with PET bales, received the European average price for the PET flakes they produced. When it comes to the assumption on 10 % reclaimer profit during the whole period it is more uncertain. Reclaimer's margin could most likely change significantly from one year to the next. Unfortunately I have not succeeded in getting information about this number. However, to test the sensitivity, let us see what will happen with the PET flake costs if the margin is set to 0 % and to 30 %, see Table 6.2 below.

	10 % [€/FU]	0 % [€/FU]	30 % [€/FU]
Reclaimer’s margin	53	0	159
PET flakes cost	475	528	369
Change		+53	-106

Table 6.2: Sensitivity analysis of PET flakes cost based on reclaimer’s margin in 2001

If we assume that reclaimer’s margin is 0, the net cost in 2001 will increase by 53 € compared to 10 % assumption used in the analysis in chapter 5, whereas the net cost will be reduced by 106 € if the margin is set to 30 %. Hence, the uncertainty of the PET flakes cost will not make a significant impact on the net cost.

The average national costs of landfill and of incineration, included transport, of non-returned PET bottles are relatively high since it is only based on costs from waste generated, transported and treated in the municipality of Trondheim. In the figure below the changes in net cost if cost of transport, landfill and incineration is doubled as well as if it is halved are shown.

	2001 [€/FU]	Doubled [€/FU]	Halved [€/FU]
Landfill cost	65	130	33
Incineration cost	40	80	20
Total	105	210	53
Change		+105	-52

Table 6.3: Sensitivity analysis of landfill and incineration cost in 2001

As we can see changed cost of landfill and incineration will not influence significantly on the system’s net cost.

In the calculations in Chapter 5 it was, based on information from the reclaimer in the system, assumed that the PET flakes every year would replace 15 % secondary steel and 85 % PET, which consisted of 75 % virgin PET and 25 % secondary PET. However, it is likely that the composition of the replaced materials changed during the time period studied. In table 6.4 below, the influence of changed composition of replaced raw material in 2001 and 2003 is presented

	Basis scenario [€/FU]	100 % steel replaced [€/FU]	100 % virg. PET replaced [€/FU]	100 % sec. PET replaced [€/FU]	33 % replace of each [€/FU]
Avoided cost 2001	-473	-15	-663	-352	-340
Net cost 2001	4062	4520	3872	4183	4195
Avoided cost 2003	-589	-33	-772	-432	-408
Net cost 2003	2758	3314	2575	2915	2939

Table 6.4: Sensitivity analysis of avoided cost in 2001 and in 2003

As we can see the assumption of what is replaced has some impact on the net cost of the functional unit of waste management of 1000 kg used PET bottle. In 2001 the net cost varied from 3872 € (100 % virgin PET replaced) to 4520 € (100 % recycled steel replaced), whereas it varied from 2575 € to 3314 € in 2003. Hence, due to uncertainty on what was actually replaced, it may very well be, in contrast to what was found in Chapter 5, that the net cost in 2001 was lower than in 2000 and that lowest net cost was achieved in 2003, and not in 2002.

6.1.3. Net GHG emissions

There are some uncertainties in the net GHG emission results as well.
In Lerche Raadal et al (2003), which is the basis for the calculations of net CO_2e in this thesis, the sensitivity analysis shows that:

- Localisation of reclaimer in Norway instead of Denmark will improve the net GHG emission balance to some extent.
- Introduction of 2 liter bottles will improve the environmental benefit of the system to a lesser extent.
- Reduced return rates will reduce the environmental benefit of the system.

The uncertainty of data applied is not discussed extensively in this study. However, there is one item of data uncertainty I think it is worth to have a look at: the assumptions of which raw material the produced PET flake replace. This choice can be justified by looking at Figure 5.3 in 5.1.3., where we can see that avoided raw material elements contribute by far the most to the overall net CO_2e balance. Even though I unfortunately, lack complete access to data used in the Lerche Raadal study, it should be possible to discuss some of the uncertainty. In the basis scenario used in the whole time period studied, it is assumed that 63,75 % of the PET flakes produced in the Resirk/PET system replaces alternative virgin PET material, whereas the remaining PET flakes substitute secondary PET or secondary steel produced in other recycling system. If we assume that the CO_2e emission from production of secondary PET and steel is 25 %[25] compared to

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[25] The 25 % estimate is partly based on visual evaluations of graphs given in Raadal et al 2001

those emitted from production of virgin PET resin, the sensitivity can be calculated. In Table 6.5 below, the influence of changed composition of replaced raw material in 2000 and 2002 is presented

	Basis scenario [kgCO$_2$e /FU]	100 % steel/PET [kgCO$_2$e /FU]	100 % virg. PET [kgCO$_2$e /FU]	50 % each [kgCO$_2$e /FU]
Avoided GHG 2000	-716	-247	-986	-616
Net GHG 2000	-562	-93	-832	-462
Avoided GHG 2002	-1578	-543	-2172	-1358
Net GHG 2002	-1253	-218	-1847	-1033

Table 6.5: Sensitivity analysis of avoided GHG emissions in 2000 and in 2002

As we can see the assumption of what raw material that is replaced has a large impact on the net CO$_2$e of the waste management 1000 kg used PET bottle. In 2000 the net CO$_2$e varies from -247 kgCO$_2$e (100 % secondary PET/steel replaced) to -986 kgCO$_2$e (100% virgin PET replaced), whereas it varies from -543 kg CO$_2$e to -2172 kg CO$_2$e in 2002. Hence, due to uncertainty of what was actually replaced it could be, in contrast to what was found in chapter 5, that the lowest environmental benefit was seen in 2000 and the highest in 2003. However, it is not very likely that material composition replaced one year is dramatically different from the one substituted the year after.

It should be mentioned that quality of the recycled product is not reflected when doing an LCA based CO$_2$e balance. Low quality recycling into for example fibers gives the same environmental benefit as high quality recycling into new PET bottles as long it replaces the same type of material, in most cases virgin PET (IFEU 2004).

6.1.4. Summary of sensitivity analyses

The largest uncertainties for both net cost and net GHG emissions are found in the calculations of which materials are assumed to have been replaced by PET flakes produced in the Resirk/PET system. In 2001 the net cost could have varied from 3872 €/FU (100 % virgin PET replaced) to 4520 €/FU (100 % recycled steel replaced). As for the avoided GHG emission the uncertainty analysis of the 2002 results shows that net GHG emissions could have varied from -218 kg CO$_2$e/FU to -1253 kg CO$_2$e/FU. The uncertainties of other calculations are more limited. After taking several uncertainty analyses into account, I would still argue that there is no doubt that eco-efficiency has increased during the 2000-2003 period. However, in contrast to what was found in chapter 5, it may be that the net cost in 2000 was higher than in 2001 and also higher in 2002 than in 2003.

6.1.5. Most contributing parameters

In 5.1 I found that the increased eco-efficiency during the period studied could mainly be explained by the parameters increased tonnage of volume participating in the system and improved return rate. The uncertainty of the calculation of the return rate is extremely low due to the fact that all sold and returned bottles in the Resirk/PET system are automatically registered and counted. As for the tonnage of participating bottles, there are slight uncertainties in terms of bottle weight, see 6.1.1.

Another question of uncertainty is the extent to which there could be other factors that are more important when it comes to explanation of the increased eco-efficiency. It could for example have been factors such as investment in new technology to reduce sorting cost or change of marketing strategy to reduce bale cost. However, even though not studied in detail, I can’t see that these or other explanations factors have been as decisive as bottle volume and return rate.

6.2. Uncertainty of interactive resource development findings

In Chapter 5 my main findings were that the changing force of sabotage produced, through friction, a reaction that lead to changes in Imsdal and interrelated resources. I have identified changes of the product Imsdal, the business unit Ringnes, the product PET bale and the facility PET material- and design specification. Some of these changes had influence on the bottle volume and on the return rate of Imsdal, and hence on the Resirk/PET system’s improved eco-efficiency. Furthermore, I found that a changing force can be distributed and create tensions and thereafter changes in interfaces and resources both immediately after and a long time after it struck. This was well demonstrated in the case of the Imsdal resource which changed rather quickly after the sabotage, and in the case of the PET spec resource, where sabotage contributed to changes 16 months after the sabotage. In this section I will briefly discuss the uncertainty of these findings.

6.2.1. Sabotage as main reason for change of Imsdal

I would argue that it is well proven that the white spirit sabotage was the main reason for the quick change of the design and material content of the Imsdal bottles, and moreover that changes in the Ringnes organisation also took place due to this incident. It could of course be questioned whether these changes, sooner or later, would have taken place in any case. Such a theory cannot be excluded, however, according to my sources at Ringnes there were no indications of such a decision at that time. It is also rather obvious that the striking force of sabotage resulted in increased interaction which again resulted in increased adaptation between Ringnes and Imsdal: The weeks after the sabotage, frequent and various activities to rescue the Imsdal brand were carried out, and the months after the re-introduction of the product showed that Imsdal and Ringnes seemed to be more connected than before. Imsdal was in many ways used to prove that Ringnes took responsibility for consumer security.

6.2.2. Increased volume and improved return rate due to increased adaptation

Other important findings were that increased interaction and adaptation between Ringnes and Imsdal, both before and after the white spirit sabotage, resulted in increased volume and possibly increased return rate of the Imsdal bottle, and that this contributed to increased eco-efficiency. As for the uncertainty whether the increased volume and return rate of Imsdal in the Resirk/PET system contributed substantially to the increase of the Resirk/PET system's overall bottle volume and return rate, I would argue that the uncertainty is extremely low. This is due to the fact that I have exact automatic registered data on the number of consumed and returned Imsdal bottles and other bottles in the Resirk/PET system. As the 0.5 and 1.5 liter Imsdal bottles were introduced right after the sabotage, I would argue that it is pretty certain that the sabotage was the major reason for the substantial increase in volume of Imsdal bottles in the Resirk/PET system. It is, however, more uncertain whether increased adaptation between Ringnes and Imsdal can explain the increase in Imsdal's return rate during the 2000-2003 period.

6.2.3. Sabotage as reason for changed PET spec

A final important finding is that the white spirit sabotage contributed to increased percentage of coloured PET bottles in the PET bale, and that this was a major reason for change of PET spec. On the issue of increased colour fraction in the PET bales, exact measurement of number of blue bottles removes any uncertainties. The question as to what extent sabotage contributed significantly to the change of the PET spec in December 2003, is perhaps more difficult to prove. As shown in chapter 5 the bale and the spec were de-adapted to a steadily increasing degree since the PET spec was introduced in June 2000 until the sabotage occurred in August 2002. Hence it can be argued that the interface between the two resource elements would have continued to be destabilized regardless of the introduction of the blue Imsdal bottles in October 2002. Norsk Resirk had plans about updating the PET spec long before October 2002. There were pushes from the reclaimer who received too many coloured bottles in the PET bales, and importers and producers reported that the PET spec was unclear, and some of them argued that it was too rigid. However, this is not an argument that the sabotage was not an important reason for the change of PET spec. All these pushes resulted in a situation were the PET spec became less and less adapted to the PET bale and other interrelated resources. Hence, many interrelated resources contributed to the destabilisation between the PET spec and these resources, which eventually resulted in the appearance of a new PET spec. The point is, however, that the impacts from many of the connected resources were stable and long lasting, whereas the sabotage resulted in an unpredictable, instant and additional force that realised the change potential the other interrelated resources had created in interaction with the PET spec.

7. Main findings, implications, and recommendations

In this final chapter I will sum up the practical and theoretical findings in this thesis. In 7.1 I will first give the answers to the four research questions I presented in chapter 1.4. In 7.2 I will present what practical and theoretical implications my thesis may have, before I give my recommendations for further work in 7.3.

7.1. Main findings

7.1.1. Eco-efficiency improved, high costs

Eco-efficiency improved
The eco-efficiency of the Resirk/PET system, calculated on the basis of the functional unit of recycling, incineration, and landfilling of 1000 kg used PET bottles, increased every year during the 2000-2003 period. The recycling rate was 28.4 % in 2000 and 72 % in 2003.

The Resirk/PET system's environmental influence, given by net emissions of greenhouse gases (GHG), improved from -562 kg CO_2e (562 kg CO_2e avoided generated) in 2000 to -1442 kg CO_2e in 2003. Production of secondary high-quality PET flakes, and hence opportunity for replacement of use of alternative virgin material, is a prerequisite for high environmental efficiency in the system.

The economic efficiency also improved during the period studied, even though the net cost of recycling, incineration and landfilling 1000 kg used PET bottles was slightly higher in 2001 than in 2000 and in 2003 compared to 2002. The net cost was reduced from 4003 € in 2000 to 2758 € in 2003. The cost element of transferring used PET bottles into PET bales contributed by far most to the overall net cost. Avoided cost, preferably of alternative virgin material, is the second most important cost element in the overall net cost.

Costly compared to other systems
If we compare the Resirk/PET system with other waste management system in Europe, we can see that the environmental efficiency is very high, whereas the cost-efficiency of Resirk/PET system is poor. The recycling rate is 3-4 times higher than systems based on collection through curbside and bringing solution, while the costs are 4-5 times higher. If comparing the current Resirk/PET system with an alternative solution where the PET bottles are included in the Norwegian national system for other plastic packaging, we have seen that the increased recycling rate in the Resirk/PET system has its price: The extra cost of reducing one tonne CO_2e in the Resirk/PET system is 2690 €, which is a lot compared to the 8 €/tonne price in the European Union emission trading system for greenhouse gases. However, recycling of PET bottles gives other benefits such as avoided littering and reduced toxic emissions from incineration, which are not include in

this calculation. Nevertheless, it can be questioned whether the Resirk/PET system can be justified under the current conditions of low volume of participating bottles. However, this may change if a substantially higher volume of PET bottles are included in the system. Hence, it cannot be concluded from this study that a deposit system as such is a cost ineffective way of organizing recycling of PET bottles.

It should be mentioned that the Resirk/PET system is not perceived costly among producers and importers. The reason for this is the fact that above a recycling rate of 50 % the administration fee they have to pay to cover the administration and running cost of the system is substantially lower than what they get in reduction in packaging fee.

7.1.2. Volume and return rate most contributing parameters

I found the total volume and return rate of PET bottles participating in the Resirk/PET system were the most influencing parameters on changes in eco-efficiency. From 2001 to 2002, for example, the volume increased from 771 tonnes to 1588 tonnes, and the return rate increased from 56.3 % to 65.2 %. This resulted in a reduction of net cost from 4062 €/tonne in 2001 to 2683 in €/tonne 2002, while the net GHG emission improved from -1082 kg CO_2e in 2001 to -1253 kg CO_2e in 2002. Increased volume of PET bottles included in the Resirk/PET system gives increased eco-efficiency due to the increased degree of economy of scale effects. Increased return rate, and hence increased recycling rate, at least up to 75 % gives improved eco-efficiency.

Since the bottled non-carbonated beverage product Imsdal was the bottle type that by far contributed most to the bottle volume in the Resirk/PET system, it was selected as the focal resource to study in detail to illuminate the changes in return rate and volume of bottles, and hence the eco-efficiency measured.

7.1.3. White spirit sabotage changed Imsdal and PET spec

Sabotage changed Imsdal and interrelated resources
Increased volume and return rate of Imsdal, which partly was a result of the white spirit sabotage and subsequent increased adaptation between Imsdal and the business unit Ringnes, contributed to increase the eco-efficiency of the Resirk/PET system. This positive impact was slightly outweighed by the fact that the quality of the PET bales was reduced due to the increased volume of blue Imsdal bottles in the bales.

Friction caused changes
The analysis of Imsdal and interrelated resources has shown that changes are difficult to predict. The more or less serious attempt of sabotage, carried out by filling white spirit into four Imsdal bottles in two different shops, resulted in unpredictable effects. By looking at friction in an interactive resource development perspective, I found that:

- The changing force of sabotage produced, through friction, a reaction that lead to changes in Imsdal's resource structure. I have identified changes of the product Imsdal, the business unit Ringnes, the product PET bale and the facility of PET material- and design specification (PET spec). It is very likely that changes in other resources can be revealed as well.
- The changing force was distributed in Imsdal's resource structure and created tensions that resulted in an immediate change of the Imsdal resource and a 16 months later change of the Norsk Resirk's PET spec.

7.1.4. IRD approach can be combined with EE and make a contribution to IE

In chapter 3 I suggested that both the quantitative approach of eco-efficiency (EE) and the qualitative approach of interactive resource development (IRD) can be important elements within the field of industrial ecology (IE). While eco-efficiency for several years has been seen as one of the cornerstones in industrial ecology, the interactive resource development approach has, to my knowledge, not applied in an industrial ecology context before. Can these two approaches be combined to make contribution to the field of industrial ecology? I would say so. By combining the quantitative eco-efficiency framework with the qualitative framework of interactive resourced development, information about how much eco-efficiency of a defined system has changed, as well as understanding of changes within the system, can be acquired. As we saw in Chapter 3 these are important aspects of Graedel and Allenby's definition of industrial ecology.

The eco-efficiency framework can be applied to calculate changes of the Resirk/PET system and most likely other waste management systems from one year to another. However, such an analysis can only to a limited extent say why eco-efficiency changes. I was, by carrying out the eco-efficiency analysis, able to identify volume and return rate as the most important reasons for improved eco-efficiency. The data gathered in the eco-efficiency analysis also helped me find that increased volume and return rate of Imsdal contributed significantly to the system's overall volume and return rate. However, the eco-efficiency framework was not able to help me to identify reasons for changes of Imsdal's volume and return rate, and for this purpose interactive resource development seemed to be an appropriate tool.

I would argue that eco-efficiency framework has brought something into the resource development framework as well. Often a focal resource in such a study seems to be more or less randomly selected, or perhaps on the basis of the researcher's interest. That is fair enough. However, if done as in this thesis, to base the selection on what is relevant for the decision maker, i.e. cost-effective recycling in the case of Norsk Resirk, a good starting point can be found by doing an eco-efficiency analysis first. Moreover, the eco-efficiency study, gives good hints on where one should look for interesting resources in terms of having an influence on the focal resource selected.

I would argue that in addition to give some contributions to both the eco-efficiency and the interactive resource development approach, this thesis should also give implications on how to combine eco-efficiency and interactive resource development:

- Eco-efficiency evaluation studies are useful to measure and track changes and to identify important resource elements.
- Eco-efficiency framework is not useful to understand the reason for changes, and to understand the dynamic of recycling systems
- By combining the eco-efficiency approach with the interactive resource development approach valuable information about dynamics of the recycling system are gained
- However, in order to really grasp the changes it is important to restrict the analysis to focus on one focal resource and only a few resource interfaces
- The focal resource should be selected on the basis of relevance according to the eco-efficiency analysis

7.2. Practical and theoretical implications

In this section I will go through what practical implications and theoretical implications this thesis may have. As for the practical implications, I will discuss efforts which could increase the eco-efficiency for waste management of PET bottles in the Resirk/PET system. Thereafter, I will discuss whether the use of the concepts of eco-efficiency and of interactive resource development to study the Resirk system may have any theoretical implications to eco-efficiency and interactive resource development, respectively.

7.2.1. Practical implications

As we have seen the eco-efficiency of the Resirk/PET system has improved considerably during the 2000-2003 period. Increased volume and return of PET bottles are important reasons for the improved eco-efficiency. However, there should still be plenty of room for further improvements. The main challenges are to further increase the volumes of bottles that are participating in the Resirk system and increase the return rate of these bottles, at the same time as the cost element of transferring used PET bottles into PET bales is reduced. In the following sections I will come up with suggestions on how such tasks may be overcome. Several of the suggestions should be relevant for other waste management systems as well.

From waste management to production

It is important to not perceive and treat used bottles or other so-called waste or end-of life material as a problem that one should get try to get rid of. The focus should rather be on looking upon this waste as a raw material that should be used to make new products. By having such a product and life cycle focus the basis for ensuring eco-efficient production, by focusing on the material stages from cradle (waste) to gate (new product) in an eco-efficient way. Rather then trying to sub-optimise each of the stages, each actor should focus on creating an efficient end product, similar to what is often done when it comes to ordinary product system.

According to Brodin (2002) actors in recycling systems have not yet succeeded to implement this production way of thinking. Various elements in a recycling system do not suit into each other in the same way as the case is for production system, making the recycling system far less efficient. Brodin states moreover that the only way to reach the same level is to perceive recycling system as production system, not as system which should get rid of waste. Even though the decision makers in the Resirk/PET system to a certain extent see this system as a recycling system where new products are created, there should be room for improvements in terms of optimizing the product cycle. By doing so PET flakes with a higher quality at a lower cost should be possible to acquire.

Further tax incentive

In order to achieve large-scale effects it is important to have a large volume[26] of end-of-life material to enter the recycling system. As for the Resirk/PET system, the cost was reduced notably when the volume of incoming bottles increased. However, still less than 2 tonnes PET bottles enter the system every year, and this low volume is, as we have seen, a reason for the costs of the system still being very high. Reduction of beverage packaging fee on one-way packaging will probably be a large incentive for producers of beverages to change from refillable glass- and PET bottles into one-way PET bottles, and include these new bottles in the Resirk/PET system. A more drastic initiative could be to remove the beverage packaging tax and deposit law completely, and let the PET bottles in the Resirk/PET system be a part of the Norwegian system for collection and recycling system for plastic packaging, Plastretur[27]. According to Røine (2005) the average cost of collecting, sorting and reclaiming used plastic packaging in the Plastretur system in 2003 was 607 €/tonne reclaimed material. Avoided costs are not included. The costs per tonne reclaimed PET in the Resirk/PET system in 2003 were 3061 €/tonne. However, the recycling rate in the Plastretur system was 21 %, while the Resirk/PET system reached 72 % recycling in 2003. There is no packaging tax, and hence no relation between recycling rate and packaging tax, in the Plastretur system.

Double deposit

In 2003 the return rate for PET bottles was 75 %, while more than 90 % of the cans in the Resirk/PET system were returned. There are two possible reasons for this difference; consumers are not to the same degree aware of the fact that there also is a deposit on PET,

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[26] This may be in contrast to the aim of waste prevention, see chapter 1. However, it may also be sustainable to increase the end-of-life volume of one material fraction to another one. Norsk Resirk argues for example that it is better that the PET bottles go through their deposit system than they go in the regular waste management system.

[27] www.plastretur.no

and consumers are not to a sufficiently high degree interested to deposit PET bottles. As the volume of PET bottles in the Resirk/PET system is very low compared to the tonnage of aluminum cans, there is not a large economic incentive to return the PET bottles. While a household in many cases may consume 10-20 cans during a month, perhaps not more than 1-2 used PET bottles will be generated. Hence, there is not much money in monthly return of PET bottles, and some consumers may not want to put effort in doing it. A higher return rate could probably have been achieved if the deposit on the PET bottles is doubled. However, this may have the negative effect that some producers will not want their bottles to take part in the Resirk/PET system because the (perceived) price the consumers have to pay for the bottles will increase. In this case the volume of the PET bottles will be lower than it otherwise would have been.

PET spec must be kept updated

In order to ensure efficiency in the various sorting, compacting and transport processes in a recycling system it is highly relevant that the end-of-life material is as recycling friendly as possible. As for PET bottles this is a question about ensuring, to as large an extent as possible that the bottles have an appropriate shape, are clear and made of 100 % PET, that the closures and labels are made of recyclable material, and that the label glue should not harm the recycling process. In general, as far as possible the main decision maker of a recycling system should have a specification that is clear on what products to accept and what not to accept. Another advantage of having a clear spec is that the participating bottles may turn out to be more similar than is the case today. If so, consumers may to a larger degree than today recognize the bottles as “a family of refundable deposit bottles”. This spec should be updated when required. It is, however, important to ensure that the spec does not restrict the volume of bottles to enter the system.

Improve collection efficiency

There seems to be a scientific agreement that higher recycling rates of plastic, at the expense of incineration with or without energy recovery and landfill, give higher environmental performance at least up to a certain recycling rate. This has also revealed to be true for the PET bottles in the Resirk/PET system. The question is whether this statement is valid also for return rates all the way up to 100 % since it is often argued that it requires more transport to collect the “last bottles” than the “first”. In the case of the Resirk system this may not be true, as there seems to be an equal opportunity for all bottles to be brought back to shops and kiosks when consumers are buying new goods. However, it is questionable if it would be correct to allocate all the consumer transport to the system for purchase of groceries, and nothing to the Resirk/PET system, for return rates above 90 %. In order to achieve such high consumer participation some transport just to deliver used bottles, without doing shopping, may be needed. In that case a 100 % return rate may not be desirable, and this may be the reason why Norsk Resirk has stated that they aim to achieve a return rate on 90-95 %, and not 100 %. Another, perhaps somewhat more controversial suggestion, is to consider leaving out return services for end-of-life products in areas where the population density is low. Collection of bottles or end-of-life material from these areas will not contribute significantly to the overall return rates. Moreover, the costs per kg of RVM operation and of transporting these materials to sorting facilities are significantly higher here. However, it must be taken into consideration which signals and other consequences such exclusion may cause.

Improve cost efficiency of information and marketing

Experiences from the Resirk/PET system reveal that it requires a lot of resources spent on information- and marketing campaigns to achieve high recycling rates. Even though informing the consumers on what and how to return end-of-life product is of high importance for ensuring eco-efficient recycling, it could be questioned whether such resources could be spent differently while at the same time achieve high recycling rates. In cases where the recycling goals are 90-95 %, and a lot of resources are put in to reach such levels, it should also be discussed whether the recycling goals should be moderated.

Increase compaction and filling degree

It should also be possible to obtain improved results on the technical side of recycling. In the case of the Resirk/PET system there are, or seems to be, cost and emission reduction potentials when it comes to:

- Increase the compaction rate of bottles in the reverse vending machines.
- Increase the filling degree of the bags connected to the reverse vending machines
- Increasing the filling degree of trucks going from the shops to the warehouses

Automatic sorting

Even though a design and material spec (in those cases where the producer responsible organiser is able to have that) could restrict the number of undesired used products to enter the recycling system, it is very likely that also less recyclable waste will end up in the recycling system. Hence, there is a need for high quality sorting to separate recyclable material from other material. Today, this is done by either manually or with automatic sorting. In the case of the Resirk/PET system there is manual sorting, however, Norsk Resirk has made calculations on whether it is profitable to invest in automatic sorting equipment which can separate PET materials from other materials and clear bottles from coloured. So far the volume of bottles has been so low that such investments cannot be justified. However, this should be re-considered if the volume increases. In any case, the empirical analysis reveals that there is a certain potential for improving the quality of the manual sorting. However, it should be kept in mind that this may increase the sorting cost.

Focus on high quality PET flakes

In order to ensure high recycling rates and high-quality recycling it is of high importance that the secondary raw material produced is of highest possible quality. Also for the economical part of the eco-efficiency ratio it is important since the quality of this material decides which material to replace and hence to include in the net cost balance. For PET the price of primary raw material is twice as high as for secondary raw material, and will hence reduce the net cost accordingly. Besides, the last decade has shown that high quality secondary raw materials are less vulnerable to price variation than low quality secondary raw materials due to seasonal changes as well as development of the raw material market. In addition to having a clear PET spec and good sorting to produce high quality PET bales, it is important that the reclaiming is of highest possible quality. As for the Resirk/PET system, the reclaimer delivers relatively high quality PET flake to the end-user market. However, the quality in the period analysed did not reach the level of being applicable for the high quality bottle market. Reclaimers wanting to deliver PET flakes or granulates to this market need a certificate showing that the facility is able to deliver material of the purest quality. Norsk Resirk should consider developing a relationship to such a reclaimer.

The importance of business relationships

A final important way to improve eco-efficiency of recycling is to encourage relationships between the various business units in the system. This could hinder sub optimization of single activities such as for instance sorting or transport. The main decision maker of the system has large potential since it has the unique position of organizing and administering the system. In the Resirk/PET system, we have seen that Norsk Resirk has taken advantage of this position and established relationship between themselves and the producers. However, in order to ensure a common understanding of the life cycle perspective, similar relationships should be encouraged between, for example, the producers and the reclaimer. Such relationships may increase the producer's awareness of using PET bottles that are preferable also from a recycling point of view. In the Resirk/PET system there is already one incident of a producer-reclaimer relationship that is based on ensuring high recyclability of the producer's PET bottles.

7.2.2. Theoretical implications

Eco-efficiency framework is appropriate for evaluating waste management systems.

Being aware of the fact that eco-efficiency has to a certain degree been applied by other authors to evaluate waste management, an important part of this thesis has though been to modify the flexible user based tool of eco-efficiency into being applicable for doing research on waste management system. This study has revealed that the original eco-efficiency framework rather easily can be modified and applied for such a purpose as long as there is a main decision maker that expresses a goal or a mission containing both environmental and economic elements. Wanting to keep eco-efficiency framework for waste management systems grounded to practical challenges, and at the same time being based in scientific fields, I am concluding that the:

- framework can be based on the original eco-efficiency approach, simplified LCA and LCC, and at the same time take the goal of the main decision maker in the waste management system into account

- modified framework should focus on being applicable for research purposes, and not first and foremost be a management tool. However, the decision maker's goal or mission should have an impact on the definition of the goal and scope of the study
- result from using the framework should be given in such a manner that it may be useful for the decision maker

Eco-efficiency equation

In the traditional eco-efficiency approach from the World Business Council for Sustainable Development (WBCSD), which is aimed to be a management tool for companies, the economical efficiency is expressed as "Product or service value", whereas the environmental efficiency is given as "environmental influence (of this product or service)". As for evaluation of Resirk/PET system, and most likely other waste management systems as well, it is more appropriate to express eco-efficiency by the economical indicator of net cost and environmental influence by for example the net GHG emission indicator or another aggregated environmental influence indicator. In order to be able to draw conclusions from an analysis, these indicators can both be expressed as stand-alone indicator or as a ratio. The values quantified by the use of the indicators can both be given in table, or, perhaps more illustrative, shown in an eco-efficiency portfolio diagram. When expressing eco-efficiency for waste management system where a substantial amount of the waste generated is recycled, the eco-efficiency can be calculated in the following way:

$$\mathit{Eco\text{-}efficiency} \equiv \frac{\mathit{Environmental\ influence}}{\mathit{Cost}} \equiv -\frac{\mathit{Net\ GHG\ emissions}}{\mathit{Net\ cost}} = -\frac{CO2e/_{FU}}{€/_{FU}} = -\left[\frac{CO2e}{€}\right]$$

Increased ratio means increased eco-efficiency. This equation is valid for net GHG emissions < 0 and net cost > 0.

Emissions from and costs of collection, sorting, transport, re-processing, recycling, incineration and/or landfill, as well as avoided emission and costs from use of alternative material, should be included in the calculations.

Sufficient to only apply a few indicators

Is it sufficient to use only two indicators to express eco-efficiency? I will try to answer this question by discussing whether the two indicators I have applied, net cost and net greenhouse gas (GHG) emission, are the appropriate and sufficient ones to reveal whether the Resirk/PET system is moving in a cost and environmentally effective direction. By applying a suggested approach within the SETAC LCC I feel fairly certain that the cost calculations, focusing on the actual running and administration costs within the system borders defined, are well taken care of. I would furthermore argue that there is no need to include more than one economic influence indicator as the net cost indicator gives a full justification to the mission of cost efficiency. As for the environmental part, where I rely on the SETAC LCA community as well United Nation Framework for Climate Change Convention, it may be questioned whether emphasis on GHG emissions solely, is sufficient. From a strictly scientific LCA point of view, I would agree that it is not sufficient. My answer would be that the framework applied here is not based on a full scale LCA. The framework is based on decision makers in waste management system, the flexible concept of eco-efficiency, and the life cycle approach. Moreover, in the case of the Resirk/PET system only one indicator for environmental performance is selected since Lerche Raadal et al (2003) have revealed that net GHG emission gives a good overall picture of the environmental performance of this system. Hence, if I had included other LCA impact categories such as for instance acidification, the eco-efficiency changes in the Resirk/PET system within the 2000-2003 period would most likely have been in accordance with what the net GHG emission indicator shown. However, it must be emphasised that this is not necessarily the case for other waste management systems. If the eco-efficiency of other waste management systems is to be studied, I therefore suggest conducting a rough pre-analysis before the indicator(s) is/are chosen. Another possibility could be to use Eco-indicator 99 (Dreyer et al 2003), which cover environmental aspects more broadly. However, we should not forget that the basic idea in the eco-efficiency framework is to have only some few indicators to be able to easily compare eco-efficiency from one year to the next. Finally, we must not forget that the aim of this thesis is to identify eco-efficiency changes, and not to quantify the exact eco-efficiency of the system.

But, if simplicity is a strong argument for choosing net GHG emissions as the only indicator, then why not apply return rate, or recycling rate, which almost fully determines the environmental performance of the Resirk/PET system and beside is easy to measure, as the one and only indicator? This has been considered, however, I would argue that achieving high recycling rates is not telling the whole story about environmental performance and it should not be a goal in itself unless one can be sure that highest possible recycling rate is preferable from an environmental point of view, see the discussion in 6.3.1

Appropriate to use goal and scope from LCA and LCC?

In the eco-efficiency framework I have stated that the goal and scope of the analysis must be defined. This includes defining the purpose of the study, functional unit, as well as the system boundaries. As mentioned many times Norsk Resirk's mission of being cost- and environmental efficient is the basis for the defined goal and scope of this study. Relying on work by Finnveden et al (2000) on LCA of waste management systems, I have excluded costs and emissions upstream of used PET bottles. This is done since these costs and emissions are not perceived relevant for Norsk Resirk, the main decision maker of the system. However, both the cost and the emissions in the defined Resirk/PET system are dependent on decisions taken both in the product system, where the PET bottles are the end product, as well as in the waste management system, where secondary PET raw material is the end product. The upstream decisions on what colour the bottles should be are for example having impacts on the costs, both of producing the bottle as well as of how to recycle it. Besides, from an environmental performance point of view, coloured bottles are not as recycling friendly as clear bottles. However, I would still argue that the costs and emissions of producing the bottles should not be included when quantifying the eco-efficiency of waste management of PET bottles in the Resirk/PET system. The downstream system borders comprise all costs and emissions until the PET are actually recycled into a new product, incinerated with or without energy recovery, or landfilled.

In Norsk Resirk's annual account balance the return rate and costs per PET bottle handled in the various stages are given. This information could very well, given that the eco-efficiency framework is designed to be a flexible one, be applied directly to quantify eco-efficiency in another way than done in this thesis. However, I would argue that the choice of connecting to the LCA and LCC scientific based functional unit way of thinking have added a consistency that otherwise would be difficult to acquire. Moreover, the functional unit way of thinking has made it possible to integrate economical performance and environmental influence, an important aim within eco-efficiency.

Another critical question is the extent to which it is realistic to speak about avoided cost and avoided emission, and in that case how much you avoid by recycling and by producing heat. The basic assumption is that secondary raw material replaces alternative use of other (primary or secondary) raw material and fuel. In my analysis I have assumed that I replace a combination of primary PET, secondary PET, secondary steel raw material, as well as oil. This assumption is based on information from the reclaimer on what type of end-user the PET flake is delivered to. However, the question on the extent to which this delivered PET flake really avoids production of alternative material or whether it comes in addition to the ongoing production still remains open.

Identification of major factors to eco-efficiency

In addition to be able to measure eco-efficiency in a good manner, the purpose of the eco-efficiency study has been to identify where in the life cycle of transformation of waste into new products the main costs and emission are found, including where to find the most important contributing factors to eco-efficiency. By looking at the graphs that show overall cost and emissions (see figure 5.2 in 5.1.2 and figure 5.3 in 5.1.3) each life cycle stage's contribution can easily be found. Bale cost and avoided GHG emissions were found to be the most contributing life cycle stages in the study of the Resirk/PET system. When it comes to the question of identifying the most important parameters to eco-efficiency, it is not possible to find this directly from use of the eco-efficiency framework. However, when carrying out LCA/LCC based research, much time is spent over a long time period on collecting quantitative data, conducting interviews or having conversations with actors involved. In this way, an in-depth knowledge making the researcher able to make (non-obvious) findings beyond the limits of the analytical framework given, appear. As for the Resirk/PET system, it became clear very early on, that the volume and return rate, which both increased every year during the time period studied, were both very decisive for the eco-efficiency performance.

Use of the framework of interactive resource development

Is the framework of interactive resource development an appropriate framework to examine changes in waste management systems? I will try to answer this question by discussing my experiences from study of changes of Imsdal and interrelated resources. Based on the eco-efficiency study, where I found that volume and return rate of the bottle that participated in the Resirk/PET system were the most important parameters, I chose Imsdal, the largest beverage fraction, to be the focal resource of the study. When studying Imsdal I found that a white spirit sabotage resulted in friction that led to (further) changes of Imsdal's volume and return rate in Resirk/PET system. In this way, the interactive development approach was applied to explain some of the reasons for eco-efficiency changes of Resirk/PET system during the 2000-2003 period. I also found that the first PET spec was attempted to be adapted to the related resource elements, in particular the PET bottles and the PET bale. However, as time went by, the characteristics of the incoming PET bottles, and hence the PET bales, changed, whereas the PET spec remained unchanged. This de-adaptation process, which eventually resulted in a new PET spec, was strengthened by the white spirit sabotage on the Imsdal bottles.

By applying the interactive resource development approach where resources are categorised into products, facilities, business units and business relationships, I was able to see some of the changes that occurred in the Resirk/PET system. However, equally important were the findings that changes do not always occur even though a resource element is outdated, as the case was for the PET spec in 2001, 2002 and 2003. Even though the PET spec only was a piece of paper and hence should be easy to change, the resource seemed to be fixed in a way that made it resistant to external influence for several years. However, there might be good reason for the lack of changes. Norsk Resirk has always been concerned with keeping good business relationships with the major producers in the system. A brutal change of the spec, for example already a year after the system and the spec was launched, could very well have caused damage that could cause larger eco-efficiency problems. It may be so that the connections between the PET spec and the business relationships between Norsk Resirk and the producers, interfaces not studied in detail, were, in contrast to the PET spec-PET bale interface, increasingly adapted during the time period. In that case, such adaptations were probably an important reason for the heaviness of the PET spec.

If we, on the other hand, look at the Imsdal bottles it seems like this resource element managed to be increasingly adapted with the surrounded resources throughout the period, even though it seemed to be exposed to larger forces than the PET spec. These observations show very well that resource elements sometimes change and sometimes do not change, and, moreover, that directly and indirectly related resources influence on both changes and lack of changes. From these analyses we should also have learnt that it is difficult to prescribe changes by referring to what is "natural"; the PET spec did not change even though it "should" seen from an efficiency point of view. The Imsdal bottle strengthened the adaptation to the business unit Ringnes even though, at a certain point in time, it looked as if the quite opposite would happen. The Resirk/PET study has taught us that changes are unpredictable; that it is difficult to see what the changes will be, where changes will occur, and what will be responsible for the changes.

When carrying out an analysis by use of the interactive resource development one usually isolates a focal resource and a few other resources to see how they, as a result of interaction between actors, influence each other. I selected to study how the focal resource Imsdal and interrelated resources influenced each other and developed in relation to each other. I did this because I, firstly, identified from the eco-efficiency analysis that high volume and high return rate was an important prerequisite for the eco-efficiency of the system. Secondly, among the many resources Imsdal was connected to, I chose to study the interface with Ringnes to see if I could reveal whether the combination of these two resource elements contributed significantly to the Resirk/PET system's bottle volume and return rate. I also studied the interface between the PET spec and PET bales in detail. There are both strengths and weaknesses of isolating an interface in this way. An advantage is that this isolation gives an ability to focus and go in depth in one interface and analyse thoroughly how the two resources interact with and influence each other. Moreover, the focused study of this interface made me aware of the interesting story and influence of the white spirit sabotage at Imsdal. Such a finding would not necessarily have come across if I had analysed more interfaces and hence would not have the opportunity to dig deeply into one.

Another strength of selecting a few interfaces to study in detail, is to avoid to come up with the rather obvious, but not very fruitful conclusion that everything is connected without being able to say anything what influences most on the development of the focal resource chosen. However, there are also weaknesses with this way of doing research[28]. The most important to mention is that I will not be able to reveal all important resources that contributed to the development of Imsdal. It is likely that also other external forces than the sabotage and other resources than Ringnes contributed to the development of Imsdal. In the case of the development, and lack of development, of the PET spec, which also was studied in detail, I found that the sabotage contributed to increasing the ongoing de-adaptation between the PET spec and the PET bale. However, by focusing on this interface, I was not able to study in detail the reason why the spec was fixed and not possible to change to prevent undesirable bottles to enter the system. As mentioned above there was probably a good for reason for this, which I was not able to catch properly when I focused on the PET bale-PET spec interface solely. All in all I would nevertheless argue that I have been able to analyse important changes in the Resirk/PET system when looking at the PET bale–PET spec interface. By having a rather open approach of starting off by looking at how these two resources influenced each other, I found interestingly enough that the PET bale seemed not to have sufficient influence on the PET spec. This changed when the increased volume of less recycling friendly Imsdal bottles arrived as a result of the white spirit sabotage on a few bottles. A study of another interface, or a less detailed study of several interfaces, may not have caught this interesting finding.

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[28] Like it is with all type of research since demarcation and isolation always is present

Resources are both being adapted and de-adapted to other resources

In the interactive resource development the phenomena of adaptation is highly emphasised. The main message seems to be that a focal resource (as well as other resources) is affected by and affects on related resources and in this way become more adapted. I have found that this corresponds to what was going on in the interface between the Imsdal product and the business unit of Ringnes. Instead of being destabilised due to the external force of the white spirit sabotage, the two resource elements started to combine more heavily than before, making the two resource elements more adapted.

When it comes to the connection between the PET spec and the PET bale, we have witnessed another story. Due to the fixed PET spec resistance to being changed, these two resource elements became less and less adapted. They became *de-adapted* as the time went by. However, even though not studied in detail, it seemed that the PET spec rather became more and more adapted with other related resource elements such as for instance the business relationship with Norsk Resirk and the producers. This tells us that a resource in a resource structure adapts to some resources whereas it de-adapts in relation to other resources as time goes on. A resource being 100 % adapted to all related resources does not exist. Adaptation with some resources will occur at the expense of connection to other resources, and this leads to changes in the resource structure.

Changing force are both stabilizing and de-stabilizing

According to Håkansson and Waluszewski (2002b) and Von Corswant (2003), a changing force on a resource element will through friction, produce a reaction that will be distributed to other resources and create tensions in resource interfaces between these resources. The effects are time dependent and the reaction will stabilise some interfaces and destabilise others. All these statements are confirmed in the analysis of Imsdal in the Resirk system: The changing force of the white spirit sabotage on the Imsdal product created a reaction that immediately started to stabilise the close interface between this resource and Ringnes Imsdal, while the later effect on the distant interface between the PET bale and the PET spec was destabilisation and de-adaptation. However, these observations were in contrast to Von Corswant (2003), which argues that the stabilising effect occurred on a distant interface whereas the destabilising effect can be observed in the close interface.

Changing forces develop resource structures

To sum up the theoretical implications of using the interactive resource development approach to analyse changes in the Resirk/PET system:

- Interactive resource development approach is useful to reveal dynamic of resource elements in a waste management system
- The theory that a changing force can be *distributed* and create *tensions* and thereafter lead to changes in interfaces and resources, both right after and a long *time* after it strikes, has been confirmed
- Changes can occur on resources which seem to be adapted as well as less adapted, i.e. in both and stable and destable interfaces

- The changing force can strengthen and accelerate ongoing processes of interaction, adaptation and de-adaptation
- Lack of interaction results in de-adaptation. Interaction seems to be a prerequisite for adaptation.

7.3 Recommendations for further work

In the final section of this thesis I will make some suggestion for further work.

When working with a subject and a case for such a long time one realises that there are a lot of things that I could have continue to research. It would for example be interesting to study the people's cognitive perception of waste, or perhaps to find a cost-efficient automatic sorting technology that can recognize and separate every bottle type, including its closure, label and label glue. However, instead of suggesting such, or other brave research tasks, I will rather recommend how the work I have done could be improved or elaborated by future research. I will make suggestion on how to extend the suggested eco-efficiency framework and the current interactive resource development framework, and I will suggest how the analyses of the Resirk/PET system can be extended.

7.3.1 Eco-efficiency framework

My first recommendation of further research on the eco-efficiency framework is to gain more experience on whether the eco-efficiency framework I have suggested could also be used for waste management in general. By doing so, potential required modifications of the framework could be identified.

Secondly, it could be worth to try to develop a framework that captures waste reduction and/or packaging waste optimisation. Such a framework could possibly answer how eco-efficiency of a system that both aims to generate as less waste as possible and at the same time need the waste as raw material to make the (large scale) eco-efficient can be measured.

Finally, as an important output of my research is to combine eco-efficiency quantification with interactive resource development understanding, I suggest that there should be done some further research to find a more standardised way on how to identify most important parameters to eco-efficiency, how to select a focal resource, and how to find out how important the focal resource is for the eco-efficiency.

7.3.2 Interactive resource development framework

I would like to see research that contributes to make the interactive resource development framework complimentary to the eco-efficiency framework. Would it be possible to identify which of the resources related to the focal resource that is contributing most to develop the focal resource and hence the eco-efficiency?

Research on making the interactive resource development framework to be more applicable for study of waste management systems, where there often is a major decision maker, would be beneficial. It is for example perhaps not appropriate to classify such a decision maker as a “simple” business unit since it has such a huge impact on the development of the system.

In similar to the eco-efficiency framework, I would also see that the interactive resource development framework should be applied to study other waste management systems. Such studies would answer whether the framework is applicable for studying waste management in general.

7.3.3 Eco-efficiency analysis of the Resirk/PET system

The eco-efficiency analysis of recycling of PET bottles in the Resirk/PET system could very well be extended. In order to examine whether the cost-efficiency of the Resirk/PET system really is low, it would for example be interesting to compare the eco-efficiency of the Resirk system in the 2000-2003 period with more (small) waste management systems for PET bottles.

It cannot be concluded from this study that a deposit system as such is not a cost efficient way of organizing recycling of PET bottles. Therefore, quality forecasts on the possible future eco-efficiency if the volume of the PET bottles is significantly increased would also make sense from a research point of view.

Another research task, which is not sufficiently covered in this thesis, is to elaborate on the relationship between the design and material content of the Resirk/PET system’s PET bottles and the eco-efficiency. How large a quantitative influence has this factor had on the measured eco-efficiency, could be an interesting research question to answer.

Another important issue could be a comprehensive study to identify the relationship between the cost of transferring used PET bottles into PET bales, the bale cost, and return rate. To what extent has the money spent on information and marketing been a success in terms of increasing the return rate of PET bottles, is a question that could be included in such a research task.

7.3.4 Interactive resource development analysis of the Resirk system

There are several research potentials on the issue of interactive resource development for those willing to collect and analyse more data. One interesting approach would be to define the important facility of PET spec as the focal resource and analyse how it is developed, and moreover identify what resources that are major in terms of influence on this development. Another relevant research contribution could be to try to identify reasons for the lower return rates for PET bottles than for aluminum cans in the Resirk system. Elaboration on the relationship between the white spirit sabotage and the return rate of Imsdal should also be welcomed.

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A. Terminology, definitions, abbreviations

APME: Association for Plastic Manufacturers in Europe

Baling; making PET bales

Barcode; placed at PET bottles to make them recognisable

Beverage container; bottle or can

Blow moulding; blowing pre-forms into bottles

Brewery; where the bottles are filled with beverage

Bottle manufacturer; where the bottle perform and bottles are produced

CBA; cost benefit analysis

Compaction; process where the volume of bottles are reduced

CO_2e; carbon dioxide equivalent

Deposit; money refunded when empty bottles are returned

Depot; facility where empty bottles are stored and sometimes compacted

Dispose; placement of waste at for example landfills

Drop off locations; igloo where waste for recycling are delivered

EE; eco-efficiency

EEA; European Economic Area

Energy recovery; incineration with heat production

EOL actor; end of life actor

ERRA; European Recovery of Recycling Association

EU; European Union

EU15; Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italia, Luxembourg, the Netherlands, Portugal, Spain, Sweden, United Kingdom

EU directive 2004/12/EC; EU's packaging and packaging waste directive

EuPR; European Plastic Recyclers

Fees; various types (handling, administration, pick-up) of cash flow in and out of Resirk

Foodgrade PET resin; PET granulates or flakes applicable for food packaging

GHG; greenhouse gas

Granulate; small pieces of for example PET

GUA; Gesellschaft für Umfassende Analysen

IE; Industrial ecology

Igloo (drop off locations); facility where used PET bottles or material for recovery are returned

IRD; interactive resource development

ISO; International Standard Organisation

Kerbside collection; collection of waste from waste bins located at households

LCA; Life cycle environmental impact assessment

LCC; Life cycle costing

Net cost; sum of all costs – avoided costs

NGO; non-Governmental organization

Non-refillable bottles: bottles that are only filled once

NPV; Net present value

NRTEE; National Round Table on the Environment and Economy

NTNU; Norwegian University of Technology and Science

OECD; Organization for Economical Co-operation and Development

One-way (PET bottle); see non-refillable

Non-claimed deposit; deposit on bottles not returned

Norsk Resirk; Producer responsible organizer of the Resirk system

Packaging taxes; static ground tax and varying environmental tax

Pellets; see granulates

PET; Poly Ethylene Terephthalate

PET bales; compacted and bundled PET bottles

PET bottle; bottle made of PET and used for beverage- or other purposes

Petcore; European PET organisation

PET flakes; secondary PET raw material

Petimeter; facility that can recognize PET bottles from barcode and shape

PET resin; PET raw material prepared to make bottle pre-forms

PET spec; specification that explain how the PET bottles should look like

Post consumer bottles; used empty bottles

Pre-form; used to make PET bottles

Primary material; virgin material

PRO: Producer responsible organiser

Reclaimer; actor that makes secondary PET flakes/granulates

Reclaiming; the process of making secondary PET flakes/granulates

Recovery; energy recovery, chemical recovery, and material recycling

Recycled product or material; product or material with a substantial content of secondary raw material

Recycling; recycle material into a product

Recycling loop; recycling system

Refillable PET bottle; bottles that are filled more than once

Resirk/PET system; The Norwegian deposit- and recycling system for single use PET bottles

Retailer; gas station, kiosk, store, supermarkets etc that sells beverages and other articles

Reuse; use bottle or other material once again for example by refilling it

RPET; reclaimed secondary PET flake ready to be recycled

RVM; return vending machine, reverse vending machine

Secondary raw material; waste prepared to be ready for making new products

SETAC; the Society of Environmental Toxicology and Chemistry

Single use (PET bottle); see one-way bottle

Sorting; separate bottles from other products and substances

UNCTAD; United Nations Conference on Trade and Development

UNFCCC; United Nations Framework Convention on Climate Change

Used PET bottles; see post consumer bottles

Value added; numerator in eco-efficiency equation

Virgin material; primary material

Waste: products or material prepared to be landfilled, incinerated, recycled, or re-used

Waste management system; system for return, collection, sorting, landilling/incineration/recycling/reusing of waste

WBCSD; World Business Council for Sustainable Development

WCED; World Commision on Environment and Development

WDNR; Wisconsin Department of Natural Resources

B. Original design- and material specification for PET bottles and cans in the Resirk system

Type of packaging to be processed, and requirements to the physical and geometrical shape and dimensions of the beverage containers to be processed through the RVM (Return Vending Machine)

Type of packaging
The materials / types of packaging included in the Resirk-system are limited to the following:
Aluminium and steel cans
PET bottles, none refillable (one way)

Cans, material;
Pure aluminium cans, pure steel cans, as well as cans with a mix of the two materials are allowed. Mixed cans have to be with steel body and aluminium lid / top (those cans will be defined as steel cans in the Resirk System).
Steel cans are not allowed thick plated and welded, but shall be deep drawn.

Cans with a “widget” inside, a small plastic gas patron containing N_2 (or CO_2 or mixed gas), are basically allowed. However, such cans should be presented by the brewery/importer to Resirk for special approval, as new unknown types may cause problems.

PET, material;
PET bottles, both clear and coloured are allowed *(NOTE: Limitations or regulations for coloured PET are under re-consideration as of December 2000).*
Plastic-materials affiliated to PET (e.g. PE-HD) will be allowed as long as the %-ratio of the material in the system compared to the total PET volume is expected to be lower than the critical value of "pollution"/mix given by the PET-recycling companies. Permits are to be applied for and granted by Resirk only.

Physical shape and dimensions
The general limitation for shape and dimensions of the containers will be the Reverse Vending Machines. Maximum sizes (diameter and length) are fixed based on the types of containers that have been on the market prior to the development of the different machines. It seems as the RVM suppliers have been following almost the same limitations of the dimensions.

Due to the registration concept used in most RVMs, the shape of the container need to be as round as possible. The RVM rotate the container while reading the barcode and this process requires a circular and symmetrical shape.

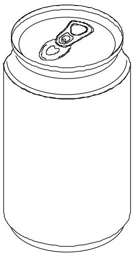
Documentation

The supplier shall present documentation for the material used (bottle, cap, label, etc.). These data-sheets are required by the recycling industry, to ensure safe and proper recycling.

Below is a guide to the required dimensions :

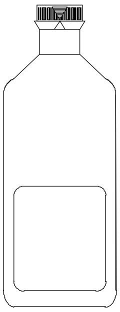
Cans:

- diameter: minimum: 50mm, maximum: 85mm
- height: minimum: 85mm maximum: 195mm
- volume: 165 - 1000 ml (provided dimension requirements are fulfilled)



PET bottles:

- diameter: minimum: 50mm maximum: 120mm
- height: minimum: 180mm maximum: 360mm
- volume: 0.3 - 2,5 l (provided dimension requirements are fulfilled)



Miscellaneous

Bottle caps : Allowed in PP - material only.

Labels : Paper, PE, PP/OPP, Silk print

Label-glue : Water solvent, but as STRONG as possible !

Bar-code placement / specifications

The bar-code can be either EAN-code (EAN-13 or EAN-8) or UPC-code. Placement and orientation of the code should be according to guidelines given in EAN-håndboken, (published by EAN Norge) section 6.
Note : The bar-code can, according to the above, be orientated both vertical and horizontal. RVM should thus be able to cross scan.
However, the producers of beverage products should preferably aim to place the code vertical to ensure the best reading results in the RVMs.

For technical requirements of e.g. print, contrast, colours, size etc. Resirk refers to, and requires, guidelines / requirements given in EAN-håndboken, section 13 - 15.

All deviations from the requirements above must be applied for to Resirk followed by a recommendation from EAN Norge.

Approval procedure for packaging

Any product / packaging applicants for participation in the Resirk System should be presented to Resirk for approval and registration at least 6 weeks before the product enters the market. Contact Resirk for details regarding sample presentation.

Tillegg til spesifikasjon for PET
Enclosure to PET specification

Korker, kapsler for PET-flasker
Caps for PET-bottles

Korken skal være i materiale PP (Polypropylen)

The cap shall be produced in PP material (Polypropylene)

Krav om materialspesifikasjon (produktdatablad)
Requirement for material specification

For alle PET-flasker som meldes inn i Resirk-systemet skal det fremlegges en material-spesifikasjon (produktdatablad) utstedt av leverandøren (emballasjeprodusenten). Dette gjelder både flasken, korken og etiketten. Våre gjenvinnere krever slik dokumentasjon.
Denne dokumentasjon vil, sammen med andre beskrevne krav, danne grunnlag for godkjenning.

For all PET-bottles entered in the Resirk-system it is required a formal material specification (product data) issued by the packaging manufacturer. This applies to the bottle, the cap and to the label. Our recycling companies require such documentation.

This documentation will, along with other requirements, be a basis for approval.

Krav om etikett-lim
Requirement for label glue

Limet som brukes på etikettene skal være vannløselig, men bør dog være så sterkt heftende som mulig. Flaskene registreres i mottak basert på lesing av strekkoden på etikettene, og det er dermed vesentlig at etiketten sitter godt. Nærmere tekniske spesifikasjoner kan vanskelig fastsettes av Norsk Resirk, men det er i alles interesse at etikettene ikke løsner.

The glue used for the bottle labels shall be water solvent, but still as strong as possible. Barcode reading will identify the bottles, and it is of high importance that the label attaches well. More detailed specifications are difficult to describe from our side, but it is in everyone's interest that the labels do not fall off.

Orientering av strekkode
Bar code orientation

Strekkoden skal være orientert vertikalt (strekene i koden dermed horisontale, som en "stige").

The bar code shall be placed vertically (i.e. bars horizontally, as a "ladder").

June 2000

Norsk Resirk AS

C. Modified design- and material specification for PET bottles in the Resirk system

Physical shape and dimension

The general limitation for shape and dimensions of the containers will be the reverse vending machines (RVMs) and the depot petimeters in the Resirk System

Every bottle with an undamaged correctly placed barcode (see section for Labels/printing below) must be readable in all currently installed well-functioning RVMs and petimeters.

The requirement is to apply with and without closure and regardless of content remains (0-30 % of total bottle volume) and any “forced position” of this content.

Rotational symmetrical shape

The RVM and petimeters rotate the container while reading the barcode and this process requires a rotational symmetrical shape.

Parallel rotational symmetrical

In addition to being rotational symmetrical, such containers will, when lying on a flat surface, have the longitudinal center axis in parallel with the surface. The point of gravity are assumed being inside the supportive area, see a in Figure 1.

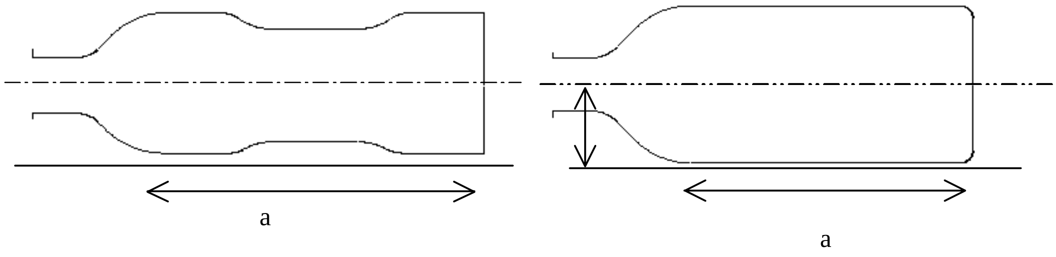


Figure 1 Parallel rotational symmetric

Non- parallel rotational symmetrical

This type of container is rotational symmetrical, but when lying on a flat surface, the longitudinal center axis is not in parallel with the surface. Due to conceptual mechanisms in the RVMs, the containers can not have a long thin neck. The containers are acceptable if the minimum diameter of the container at the end of the supportive contact edge is above 50 mm, if the angle between the surface and the longitudinal center is less than 25^0, and if the highest peak of the lying container is maximum 120 mm.

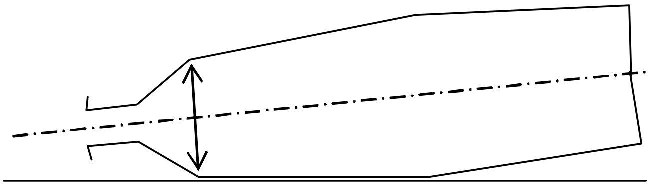


Figure 2 Non-parallel rotational symmetric

Stable resting surface

In order to ensure bar code readability, the container must have a resting surface (as in figure 1 and 2) which must cover minimum 50 % of the bottle. If the resting surface does not cover 50 % of the container, at least two points of rotation, placed on the top and the bottom of the main body of the container, is required. The test for correct container behaviour is to place the bottle on its side and check that the container is resting in a flat and stable position, please see illustrations below.

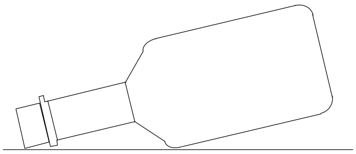
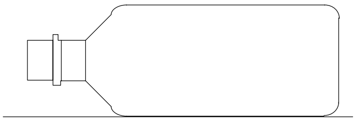
	
Incorrect container behaviour. The container is not resting in a flat and stable position.	Correct container behaviour. The container is resting in a flat and stable position.

Figure 3: The container must have a stable resting surface

If forcing the neck section of a container (with or without the cap) towards a flat surface the container should *go back* to a flat, horizontal position on its horizontal flat main body section completely automatically by gravitational force when no external force is being applied to the container.

Required weight and dimensions for PET bottles

Only relatively thin walled PET is accepted; defined by maximum 2 x the weight of the average weight of that size bottle.

Maximum sizes (diameter and length) are fixed:

Dimension	Minimum	Maximum
Diameter	50 mm	120 mm
Height:	130 mm	360 mm
Volume	250 ml	2500 ml

Material

Only Mono layer PET-A is accepted. PET cans with aluminum lid are not accepted.

If documented[29] secondary (recycled) PET material is applied in the bottle, the ordinary administration fee[30] will be reduced in accordance with the percentage amount of recycled material applied, i.e. 25 % recycled material in the PET gives 25 % reduction in ordinary administration fee.

Colour

All bottle colours are allowed. However, the administration fee will be differentiated in accordance with the extra cost of sorting[31] not-clear bottles out and, additionally, the reduction of material price[32] for such bottles.

Clear bottles
No extra administration fee

Transparent blue bottles

Extra administration fee: 12 øre in extra sorting cost + 3 øre in reduced material value = 15 øre/bottle.

Alternative calculation[33] based on price reduction for mixed clours bale give an extra administration fee of 10 øre/bottle

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[29] The beverage producer must provide Norsk Resirk this documentation

[30] Ordinary administration fee is based on clear PET bottles with PP cap.

[31] Sorting cost is based on investment- and operation cost of an automatic sorting facility. Annual cost is estimated to be in the range 1.500.000 NOK/year. With approximately 400 ton not-cleared bottles expected to be sorted out in 2003, the cost per bottle (estimated average weight of 35 g) will be: 1.500.000 NOK/400.000 kg x 0,035 kg/per bottle = approx 12 øre per bottle.

[32] Prices (July 2003, according to PCI) for clear bottles is in a range from € 125-200 € (average € 165, transparent blue is € 50-€65 (average €60), while coloured/opaque bottle is nearly 0 (Expladan).Transparent green and transparent brown is somewhere in the middle, let's say € 25.
Material values (average 35 g bottle)
Clear bottles: €165/ton x 35g /bottle x 1 e-6 ton/g x 8.33 NOK/€ (per 20.08.2003) = 0,047 NOK/bottle (= ca 5 øre/bottle).
Transparent blue bottles: 0,047 x 60/165 = 0.017 NOK (=3 øre less than for clear)
Transparent green and brown bottles: 0,047 x 25/165 = 0,007 NOK. (= 4 øre less than for clear)
Opaque coloured bottles: 0 (=5 øre less than for clear)

Suggestion: 10 øre extra administration fee per bottle

Transparent green and –brown bottles and opaque coloured bottles
Extra administration: 12 øre in extra sorting cost + 4-5 øre in reduced material value = 16-17 øre/bottle.

Alternative calculation based on price reduction for mixed colours bale gives an extra administration fee of at least 15 øre/bottle

Suggestion: 15-20 øre extra administration fee per bottle

Plasma Coatings

Allowed, however bottle to bottle/food grade (B2B) recycling documentation from bottle supplier is needed
Examples.: Actis, BestPET, Glaskin

Co-injection

Allowed only if B2B recycling documentation from bottle supplier is provided.
EVOH and Nylon are not accepted.

Additives

Allowed, however B2B recycling documentation from bottle supplier is needed.
Examples: scavengers, nanocomposites, UV-stabilisers, AA-blockers

Barrier resins

Not accepted.
Examples: PEN, PAN, blends of PET and other materials.

Spray/dip coatings

Not accepted
Example: PPG epoxy

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[33] Alternatively the reduced price for the entire mixed unsorted tonnage, must be allocated to the coloured bottles. For the present colour mix this will give approx 10 øre and at least 15 øre extra administration fee for transparent blue and other bottles respectively. Calculation will be provided at the meeting on 28 August

Base-cup and other attachments

Only clear base cup/other attachments are fully accepted.
Use of not-cleared PET, HDPE, PP and other B2B recyclable documented material give an extra administration fee on 0,1 øre/gram attachment[34].
Welded PET is not accepted.

Labels/printing

Barcode orientation/placement/specifications

Placement and orientation of the code should be according to guidelines given by EAN International. The bar-code shall be orientated as a “ladder” (number vertical, bars horizontal) The barcode should preferably be placed on the side of the main body of the beverage container.
Please see EAN International specifications for technical requirements of print, contrast, colours, size etc. The barcodes should follow the requirements set for automatic reading systems.
Bar Codes should also comply to ISO/IEC 15416 -“Bar code print quality test specification - Linear symbols” for quality measures, contrast and readability.

When a container is resting on its surface (see Physical shape and dimension section above), the barcode on the container should be presented with no (0 degree) tilt angle relative to this surface plane. Exceptions to this may however be allowed depending upon individual testing by the RVM vendors.

Deposit

The deposit symbol must have a minimum width of 15 mm, must be well visible and should be placed on the bottle label.
Se separate manual: “Hand book for deposit symbol”

Type of label

General: The density of the sleeve must be below 1.0. Tearing off the label for marketing or other reasons, should not be requested.

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[34] This is based on a 50 % reduction of the material value/gram of a clear PET bottle

Size of labels/sleeves

Due to automatic sorting reasons, maximum 75 % of the bottle surface may be covered by sleeves, labels or other attachments. If exceeding this limit, the bottle will be given an extra administration fee as a opaque coloured bottle, see the colour section above

Adhesive (glued) labels

Only Paper and PE is allowed. B2B recycling documentation is needed for other materials.

Roll (wrap around) labels

OPP is allowed. For other material, B2B recycling documentation is required.

Stretch sleeve

PE is allowed. B2B recycling documentation is needed for other materials

Shrink sleeve

OPP is allowed. B2B Recycling documentation is required for other materials. PVC, PET-G and OPS is not allowed

Metallic sleeves/labels

Sleeves and labels containing metallic are not allowed

Printing/Colour

Direct printing on bottle, colours containing heavy metals, and bleed labels are not allowed.

Adhesive

So strong that it is not removed before deposited
Water-soluble adhesive is preferred. Recycling documentation is needed for other adhesives, included solvent based (synthetic hot melt) glue.

(Another option is to threat bottles with non-recyclable friendly glue as non/partly recyclable and give them an additional administration fee based on cost to remove, 0 material value, and cost for Resirk to get rid of)

Closure/liner

Closure (basic part)

The closure should preferably be PP. Closures of HDPE[35] and other material that is documented recyclable is accepted at an additionally administration fee of 0.01 NOK.
Aluminium or other metals are not accepted. (Exception: If metal closure is a "crown cap", which will not follow the bottle after use, it is allowed)

Closure cap

The closure cap should preferably be PP. Closure cap of HDPE and other material that is documented recyclable is accepted at an additionally administration fee of 0.005 NOK.
Aluminium or other metals are not accepted.

Closure valve

The closure valve should preferably be PP. Cap of HDPE and other material that is documented recyclable is accepted at an additionally administration fee of 0.01 NOK.
Aluminium or other metals are not accepted.

Liners

Liners in closure valve (inside the cap) and in closure (on bottle neck) should be avoided or made of PE or EVA. PVC and Silicon is not allowed. Peel of Alu film/seal can be accepted if it can be proved/documented that these always are removed by the consumer.

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[35] The material value of HDPE is lower than for PP. The sales price for PP mixed with more than 20 % HDPE or other polyolefins are negative (1 DK/kg). If we assume a value difference on 4.00 NOK/kg on pure PP and a mix, and that closure (basic part weigh 2,5 g, the closure valve 2 g and the closure cap 1 g) the extra administration fee will be 4, 00 NOK/kg x 0,0025 kg = 0,01 NOK = 1 øre for the closure. The extra adm.fee for the closure valve will thus be 1, while 0,5 øre extra must be paid for a closure cap in other (accepted) materials than PP.

D. Eco-efficiency basis

The aim of this appendix is to show the underlying basis for numbers and assumptions applied in chapter 4.1 and in chapter 5.1

Material flow

Table D.1 shows the annual consumption of PET bottles, the return rate, as well as the fraction going to recycling, energy recovery and landfill.

Year	Used bottles [tonne]	Return rate [%]	Recycling [%]	Energy recovery [%]	Landfill [%]
2000	351	29,6	28,4	23,6	48,0
2001	771	56,3	54,0	15,2	30 ,8
2002	1588	65,2	62.6	12,3	25,1
2003	1695	75,0	72.0	9,2	18,8

Table D.1: Material flow of the PET bottles in the Resirk/PET system 2000-2003

The functional unit (FU) of the analysis is: Reclaiming, energy recovery, and landfilling of 1000 kg PET bottles from consumption in the Norwegian deposit system
Based on this functional unit and the table above, the material flow per FU is found, see Table E.2, below

Year	FU [kg]	To PET bales [kg]	To PET flakes [kg]	To Energy recov. [kg]	To Landfill [kg]	Avoided virgin PET [kg]	Avoided recycled PET [kg]	Avoided recycled steel [kg]	Avoided oil [kg]
2000	1000	296	284	236	480	181	60	43	137
2001	1000	563	540	152	308	344	115	81	88
2002	1000	652	626	123	251	399	133	94	71
2003	1000	750	720	92	188	459	153	108	53

Table D.2: Material flow of the PET bottles in the Resirk system 2000-2003 [kg/FU]

<u>Weight of bottles</u>
The weight of bottles is calculated on the basis of estimated average weight of the bottles sold to consumer (Norsk Resirk's annual reporting to SFT 2001-2004). The weight in 2000 and 2001 was 35 grams, while the average weight in 2002 and 2003 was 35.7 grams (Norsk Resirk's 2001-2004 annual report sent to Environmental protection agency of Norway). These average weights are used to calculate tonnes registered sale of bottles by producer and importers and, moreover, to find tonnes RVM- and petimeter registered bottles returned by consumers to shops in the years 2000-2003.

The caps and labels of the bottles are not included in the analysis

Return rate and PET bales produced

The return rates in Table D.2 are given by Norsk Resirk and calculated on the basis of number of bottles in the deposit system and number of bottles registered at reverse vending machines and petimeters (Norsk Resirk 2001 2004, annual account). It is assumed that all bottles returned became PET bales. The amount of PET bales produced is calculated on the basis of the functional unit of 1000 kg consumed bottles as well as return rate. Hence a return rate of 29,6 % in 2000, shown in Table D.2 above, gives 296 kg PET bales produced in 2000. A similar logic is applied to calculate the material flow to production of PET flakes, to energy recovery, landfill, avoided virgin PET, avoided primary PET, avoided secondary PET (PET flakes), avoided steel and avoided alternative use of oil for energy production, see Table D.2 above.

Recycling rate and PET flakes produced

The recycling rate, the ratio between the mass of PET flakes produced and applied in new products and mass of PET bottles consumed, is calculated on the basis on a previous study on environmental evaluation of recyclable and refillable PET bottles used beverage packaging in Norway (Lerche Raadal et al 2003). In this study it is estimated that 4 % of the mass of the bottles returned are lost before becoming secondary PET raw material. All the material loss takes place in the last stage of the recycling system where PET flake is produced from PET bale. No material loss is assumed in the stages from returned PET bottles to PET bales. A material loss of 4 % is estimated for all the years 2000-2003.

Energy recovery and landfill

The PET bottles that are not being recycled are incinerated or will end up at landfills. It is assumed that all these bottles were thrown in waste bins in households. Based on the material flow of the total amount of waste from Norwegian households in 2001, it is assumed that 67 % of the bottles not being recycled were deposited at landfill, while 33 % was energy recovered in 2000-2003 (Statistics Norway 2001)

Avoided production of PET and recycled steel, and avoided use of oil.

According to the reclaimer who has received PET bales from Norsk Resirk most of the time since the system was established, 15 % of the secondary material of PET flakes will replace recycled steel for production of strapping whereas 85 % will replace PET for production of packaging or fibre products. It is assumed that average European PET raw material, which consists of 75 % primary (virgin) material and 25 % is secondary (recycled) material, is replaced. It is moreover assumed that the secondary PET raw material produced is appropriate for the same user area as the virgin material. All assumptions are based on Lerche Raadal et al (2003).

It is assumed that PET bottles applied for district heating production will replace alternative use of oil. This is based on the fact that waste incineration plants producing district heating use oil if they have less waste available or if the energy content of the incoming waste is too low (TEV 2001). In order to find how much oil the PET bottles replace, the heat value of PET and oil must be compared. Heat values and density of oil is found in APME (2001):

Heat value of oil: 12.4 kWh/liter x 0.9 kg/l = 11.2 kWh/kg
Heat value of PET: 23 MJ/kg / 3.6 kWh/MJ = 6,4 kWh/kg
Need hence (6.4 /11.2) kWh/kg = 0,58 kg oil to replace 1 kg PET

Net cost

Net Cost, the indicator for economical efficiency, of the system is found by adding costs from all stages involved in recycling, energy recovery and landfilling of 1000 kg consumed PET bottles, subtracted avoided cost given as sales price of the alternative material- and energy production replaced. All costs are adjusted for an estimated annual price increase on 2.5 % taking 2000 as the basis year for the calculations. The relationship between the Norwegian currency NOK and € in 2000-2003 is set to 1 € = 8.00 NOK.

The costs are divided into:

- costs of transporting used bottles to shops
- costs of producing the PET bales from used bottles
- cost of producing PET flakes from PET bales
- costs of producing district heating from PET bottles
- costs of landfill of PET bottles
- avoided costs of alternative raw material production
- avoided costs of alternative oil for district heating.

Costs of transporting used bottles to shop
Assume no costs from this activity since the reason for consumers to drive to the shop is to do shopping, not to return the bottles (Lerche Raadal et al 2003).

Costs of producing PET bales from used PET bottles
The various costs involved to produce the bale are solely based on Norsk Resirk's annual accounts (Norsk Resirk 2001-2004), and are calculated on the basis of Resirk's internal allocation methods which are mainly based on a combination of volume and mass of bottles and cans handled (Norsk Resirk 2001-2004). Norsk Resirk is responsible for the costs of transferring returned PET bottles into PET bales delivered to the reclaimer's gate. I have data for Norsk Resirk's running costs and administration costs as well as revenues from sale of PET bale to reclaimers available.

Running costs

The following running costs are given in Norsk Resirk’s annual balance for 2000-2003 (Resirk 2001-2004):

- Payment to detailers/gas stations/kiosks
- Payment to pick-up performed by wholesaler
- Hire of containers
- Transport wholesaler to depot
- Payment petimeter, third party
- Baling, sorting, third party
- Other treatment at depot
- Freight costs sold PET bale
- Other running expenses

Administration costs and depreciations

The following running costs are given in Norsk Resirk’s annual balance 2000-2003 (Resirk 2001-2004):

- Salaries and personnel costs
- Marketing, information and education
- Communication with reverse vending machines
- Other costs
- Depreciations

In Table D.3 below the costs for transferring used PET bottles into PET bales in 2000-2003 are given below.

	2000	2001	2002	2003
Returned PET [kg/FU]	296	563	652	750
Running costs [NOK /FU]]	7887	14031	11430	14458
Admin and depr. costs [NOK/FU]	24169	19483	11499	9039
PET bales [NOK/FU]	32056	33514	22929	23497
PET bales [Euro/FU]	4007	4189	2866	2937

Table D.3: Running- and administration costs of producing PET bales

<u>Costs of producing PET flake from PET bales</u>

The costs of production and delivery of PET flakes when using PET bales as incoming material are given in Table D.6 below.

Unfortunately, costs data for the reclaiming process to produce PET flakes, the secondary raw material and final product of the recycling system, are not accessible. However, if we assume that the reclaimer has a margin of 10 %, the costs can be found by the following equation:

Flake costs = PET flake price (delivered) – PET bale prices (delivered) – 10 %

The PET bale price is found in Norsk Resirk's annual accounts, while the PET flake price is based on average European prices (PCI 2000-2004).

Assume that European prices given in the table below are representative (PCI 2000-2004). The annual price is found by taking the average of Q1-Q4. No flakes were produced before Q3 in 2000

	Q1	Q2	Q3	Q4	Average price
2000	-	-	440-630	450-600	554
2001	480-650	440-630	560-945	510-920	651
2002	340-750	400-800	400-750	400-600	545
2003	450-750	500-650	500-700	550-650	600

Table D.4: European price for PET flake (delivered) 2000-2003

	2000	2001	2002	2003
PET flake (delivered),	554	651	545	600
PET bale (delivered)	96	118	30	43
10 % margin (PET flake-PET bale)	46	53	52	56
Cost to produce PET flake from PET bale	409	475	464	500
Total flake cost, incl price adjustment	440	499	476	500

Table D.5: Calculations of costs to produce PET flake from PET Bale 2000-2003 [€/tonne]

	2000	2001	2002	*2003*
PET flake cost [€/tonne]	440	499	476	*500*
Produced per FU [kg]	284	540	626	*720*
PET flake cost [€/FU]	*125*	*269*	*298*	*360*

Table D.6: Calculations of costs to produce PET flake from PET Bale 2000-2003 [€/FU]

Costs of producing district heating from PET bottles

The costs of pick up at households and incineration PET bottles are given in Table D.7 below.

Distribution of district heating is not included. It is not included when calculating avoided costs of use of oil below.

Costs of producing energy = pick up costs waste + costs of producing district heating

Pick up costs in 2000: 597 NOK/tonne (Eik et al 2002)
Production of district heating in 2000: 1383 NOK /tonne (Eik et al 2002)

Assume that both pick up costs and district heating are the same in the whole 2000-2003 period, adjusted for an annual price increase of 2.5 %.

	2000	2001	2002	2003
PET to district heating [kg/FU]	236	152	123	92
Pick up costs [NOK/FU]	154	95	75	55
Production costs [NOK/FU]	351	220	174	127
Cost district heating [NOK/FU]	505	315	249	182
Cost district heating [€/FU]	63	39	31	23
Price adjusted [€/FU]	63	40	33	25

Table D.7: Costs of pick up incineration of PET bottles 2000-2003

Costs of landfill of PET bottles

The costs of pick up at households and landfill of PET bottles are given in Table D.8 below.
Cost of landfill (Lerche Raadal et al 2001): 1067 NOK/tonne in 2000
Assume costs are 1067 NOK/tonne in the whole 2000-2003 period, adjusted for an annual price increase of 2.5 %.

	2000	2001	2002	2003
PET to landfill [kg/FU]	480	308	251	188
Pick up costs [NOK/FU]	287	184	150	112
Cost landfill [NOK/FU]	512	329	268	201
Total cost landfill [€/FU]	100	64	52	39
Price adjusted	100	65	54	42

Table D.8: Costs pick up and landfill of PET bottles 2000-2003

Avoided cost of alternative raw material production

The avoided costs are calculated on the basis of the price of the raw material replaced; average annual European market price (delivered) for PET flake (secondary material) (PCI 2000-2003) and for PET virgin (primary material) 2000-2003 (PCI 2000-2003), as well as for sorted and baled steel cans (secondary steel) directly applicable for re-melting and production of strapping (WDNR 2005**)**.

Virgin PET (delivered)

Avoided cost of alternative production of virgin PET is given in table D.10 below.

Assume that European prices given in the table below are representative (PCI 2000-2004). The annual price is found by taking the average of Q1-Q4. No avoided production of virgin PET before Q3 in 2000

Average prices include 2.5 % annual price increase, with 2000 as base year

	Q1	Q2	Q3	Q4	Average
2000	-	-	990-1200	980-1180	1171
2001	990-1200	1040-1300	1173-1388	1007-1253	1228
2002	1020-1160	1155-1360	1046-1194	1050-1160	1172
2003	920-1220	930-1290	900-1130	1010-1175	1072

Table D.9: PET virgin prices 2000-2003 [€/tonne]

	2000	2001	2002	2003
PET prices [€/tonne]	1171	1228	1172	1072
Avoided mass kg/FU]	181	344	399	459
Avoided costs [€/FU]	212	422	468	492

Table D.10: Avoided costs of PET virgin 2000-2003

Secondary PET prices (delivered)

Avoided cost of alternative production of secondary PET is given in Table D.12 below.

Assume that European prices given in the table below are representative (PCI 2000-2004). The annual price is found by taking the average of Q1-Q4. No avoided production of virgin PET before Q3 in 2000

Average prices include 2.5 % annual price increase, with 2000 as base year

	Q1	Q2	Q3	Q4	Average Price
2000	-	-	440-630	450-600	554
2001	480-650	440-630	560-945	510-920	651
2002	340-750	400-800	400-750	400-600	545
2003	450-750	500-650	500-700	550-650	600

Table D.11: Secondary PET prices 2000-2003 [€/tonne]

	2000	2001	2002	2003
PET prices [€/tonne]	554	651	545	600
Avoided mass [kg/FU]	60	75	133	153
Avoided costs [€/FU]	33	49	72	92

Table D.12: Avoided costs of secondary PET 2000-2003

Secondary steel (delivered)

Avoided cost of alternative production of secondary steel is given in Table D.14 below.

Assume sorted, baled steel cans to be ready for melting furnace to be the material that are replaced by PET flakes.

No European price for the 2000-2003 period available. Assume price info from the Wisconsin Department of Natural Resources (WDNR 2005) to be representative for the European market.

The averages price shown are included 2.5 % annual price increase, with 2000 as base year

Assume 1 € = 1 $ for the 2000-2003 period

	Jan	April	July	October	Average price
2000	-	-	40	32	39
2001	29	26	24	29	28
2002	30	35	46	48	41
2003	45	47	46	48	46

Table D.13: Secondary steel prices 2000-2003 [€/tonne]

	2000	2001	2002	2003
Steel prices [€/tonne]	39	28	41	46
Avoided mass per FU [kg]	43	81	94	108
Avoided costs per FU [€]	2	2	4	5

Table D.14: Avoided costs of secondary steel 2000-2003

Avoided cost of alternative fuel for incineration with energy production.

Avoided cost of alternative fuel at the waste incinerators is given in table D.15 below.

It is assumed that waste incinerators with energy recovery apply oil as an alternative incoming PET (TEV 2001). Hence the price of oil is the avoided cost when PET bottles are incinerated. Based on information in Lerche Raadal et al (2001) the price of oil can be calculated to: 1200 NOK/ (550 kg/1000 kg x 0,72 (fraction incineration)) x 0,8 (fraction internal costs) = 2424 NOK/tonne in 2000

Assume constant price in 2000-2003, adjusted for 2.5 % price increase

	2000	2001	2002	2003
Avoided oil [kg/FU]	137	88	71	53
Cost oil [NOK/FU]	358	224	181	128
Cost oil [€/FU]	45	28	23	16
Price adjusted [€/FU]	45	29	24	17

Table D.15: Avoided costs of oil 2000-2003

Avoided cost

The avoided cost, included all the various avoided cost elements, is given in Table D.16 below.

	2000	2001	2002	2003
Virgin PET	212	422	468	492
Secondary PET	33	49	72	92
Secondary steel	2	2	4	5
Oil	45	29	24	17
Total avoided	292	502	568	606

Table D.16: Avoided costs 2000-2003

Net cost

The net cost of recycling, energy recovery and deposit of 1000 kg consumed PET bottles in the Norwegian deposit system in the years 2000, 2001, 2002 and 2003 is given in Table D.17 below

	2000 [€/FU]	2001 [€/FU]	2002 [€/FU]	2003 [€/FU]
Bale cost	4007	4190	2866	2937
Flake cost	125	269	298	360
Cost district heating [€]	63	40	33	25
Cost landfill [€]	100	65	54	42
Avoided cost	292	502	568	606
Net cost	4003	4062	2683	2758

Table D.17: Net cost 2000-2003

Net CO_2e

Net CO_2e, the indicator for environmental efficiency of the PET bottles in the Resirk system, is found by adding greenhouse gas emissions from all stages involved in recycling, energy recovery and landfill of 1000 kg consumed PET bottles, subtracted avoided emissions from the alternative material- and energy production replaced.

The CO_2e are calculations divided into:

- CO_2-emissions from transport, RVM and baling
- CO_2-emissions from flake production
- CO_2-emissions from incineration
- CO_2-emissions from landfill
- CO_2-emissions from avoided oil production
- CO_2-emissions from avoided raw material production

CO_2-emissions from transport, RVM and baling

The following stages are included:

Return of used bottles.
Assume no emissions from this activity since the reason for consumers to drive to the shop is to do shopping, not to return the bottles (Raadal 2003). The emissions should therefore be allocated to the shopping which is beyond the system boundaries

Shops to wholesalers
Data is provided by Lerche Raadal et al (2003)

Wholesaler to baling depot
Data is provided by Lerche Raadal et al (2003)

Baling depot to reclaimer
Data is provided by Lerche Raadal et al (2003)

Operation of reverse vending machines and petimeters
Data is provided by Lerche Raadal et al (2003)

Sorting and baling at depot
Data is provided by Lerche Raadal et al (2003)
For bottles being returned and transported to reclaimer data is provided by Raadal et al (2003)

It is assumed that emissions of CO_2e per kg operated in RVMs/petimeter, transported and baled in the Resirk system in 2000, 2001, 2002 and 2003 is similar to CO_2e per kg in Lerche Raadal et al (2003). Based on information in Lerche Raadal (2003, page 25) the net CO_2e can be found:

CO_2e per kg baled = - 3.7 kg CO_2e /(37.1 kg PET bottles x 0.973) = 0.10 kg CO_2e per kg baled

Transport from households to incineration/landfills

For bottles not being returned and hence end up in the curbside system at households where it is assumed that it is picked up and transported to incineration and landfill data is provided by Eik et al (2002) where it is found that the trucks use 1.9 liter diesel/km and that it picks up 1869 kg per trip to incineration and landfill. Moreover, I estimate that the average transport distance from pick up to incineration/landfill in Norway, included return transport, is 50 km.

Diesel consumption per pick up truck: 1.9 liter diesel/km x 50 km = 95 liter
Diesel consumption per kg waste transported: 95 liter/1869 kg = 0.05 liter per kg
Emission factor diesel: 2.5 kg kg CO_2e /liter diesel (APME 2001)
Emission pick up waste: 0.05 liter per kg x 2.5 kg = 0.13 kg CO_2e per kg transported

The total greenhouse gas emissions from transport, RVM/petimeter operation, sorting and baling is: 0.10 kg CO2e + 0.13 kg CO2 = 0.23 kg CO_2e per kg bale

CO_2-emission production of PET flake

It is assumed that emissions of CO_2e per kg produced PET flake from PET bale in the Resirk system in 2000, 2001, 2002 and 2003 is similar to CO_2e per kg in Eik et al (2002). Based on information in Eik et al (2002) the CO_2e is:

143 kg CO_2e /540 kg PET flakes = 0.26 kg CO_2e per kg PET flakes produced

CO_2e -emission incineration

It is assumed that emissions of CO_2e per kg incinerated PET bottles in the Resirk system in 2000, 2001, 2002 and 2003 is similar to CO_2e per kg in Raadal et al (2003). Based on information in Lerche Raadal et al (2001) the CO_2e is:

800 kg CO_2e/(550 kg x 0.72) x 0.56/0.76 = 1.49 kg CO_2e per kg incinerated PET bottles

CO_2e -emission from landfill

Degradation of PET bottles into CO_2 (aerobic degradation) or CH_4 (anaerobic degradation) is an extremely slow process which will take several hundreds of years. These emissions are therefore not included in this study.

Avoided CO_2e emissions from alternative raw material production

As mentioned above it is assumed that 85 % of the PET flake produced replace use of alternative PET raw material (75 % virgin and 25 % recycled), whereas 15 % of substitute production of secondary steel. It is further assumed that avoided emissions of CO_2e per kg replaced in the Resirk/PET system in 2000, 2001, 2002 and 2003 is similar to CO_2e per kg in Lerche Raadal et al (2003). Based on information in Lerche Raadal et al (2001) the CO_2e is:
CO_2e per kg recycled = - 96.2 kg CO_2e /37.1 kg PET bottles = 2.78 kg avoided CO_2e per kg PET

However, in the calculations above the reclaiming process is also included. By subtracting the calculated emissions from PET flake production, see above, the avoided greenhouse gas emissions from alternative raw material production is:
2.78 kg CO_2e/kg – 0.26 CO_2e/kg = 2.52 kgCO_2e/kg PET

Avoided CO_2e emissions from alternative fuel

It is assumed that avoided emissions of CO_2e per kg replaced oil in the Resirk/PET system in 2000, 2001, 2002 and 2003 is similar to CO_2e per kg found in Lerche Raadal et al (2001). Based on information in Lerche Raadal et al (2001) the CO_2e is:

1000 kg CO_2e /550 kg x 0,72 = 2.50 kgCO_2e/kg PET

Net CO_2e emissions

In Table D.18 below the calculations of net avoided emissions is shown

	CO_2e /kg	2000 [kg/FU]	2001[kg/FU]	2002[kg/FU]	2003 [kg/FU]
Transport, RVM, baling	0,23	0.23x296=68	0,23x563=129	0,23x652= 150	0,23x750= 173
Flake prod.	0,26	0,26x296=77	0,26x563 = 146	0,26x652 =170	0,26x750 = 195
Incineration	1.49	1,49x236=352	1,49x152= 226	1,49x123=183	1,49x92= 137
Landfill	0	0	0	0	0
Avoided oil production	2.50	-2.50 x 137= -343	-2.50x88= - 220	-2.50x71= -178	-2.50x53= -133
Avoided raw material production	2.52	-2.52 x 284= -716	-2.52x540= -1361	-2.52x626= -1578	-2.52x720= -1814
Net avoided CO_2e		-562	-1080	-1253	-1442

Table D.18: Emissions and avoided emissions of waste management of PET bottles in the Resirk/PET system 2000-2003