A SYSTEMS APPROACH TO EXTENDED PRODUCER RESPONSIBILITY

Economic efficiency and environmental effectiveness for packaging in plastic industry in Norway

By

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Abstract

This paper will, through a theoretical discussion of efficiency and effectiveness, present a model for a recovery system. The plastic packaging recovery system in Norway is described, and despite the lack of empirical data, the economic efficiency for the system will be shown and discussed, based on this model. A discussion will also been carried out on environmental effectiveness showing that the Norwegian plastic recovery system has to focus to a larger extend on the use of non-renewable resources and on the effects of loss of energy and materials to the recipients. In other words, it is strongly needed to analyse what is the optimum recovery ratio in an economic and environmental context. A positive element in the Norwegian system is, however, the focus on developing a market for the recovered materials.

Keywords: Efficiency, effectiveness, producer responsibility and systems approach

Introduction

In every science there are at least two aspects that are taken into account when building a model to describe reality. First, the model has to be as realistic as possible, which inevitably adds complexity. Second, the model must be simple enough to be usable.[4] These two aspects are inherently contradictory. In addition, it is not easy to discover whether it is the world or the model that is described. Traditional environmental thinking has been dominated by the assumption that industrial and natural ecosystems are two separate parts with neither interaction nor interface. This model is an over-simplification which no longer is sufficient for managing environmental challenges. As noted in the literature on industrial ecology (Ehrenfeld, 1994; Sagar and Frosch, 1997), the interaction between human-made and natural ecosystems, has to be taken into consideration. What is happening within the defined system is important, but equally important are the interactions between the system and its surroundings. This is the basic idea in systems thinking (Asbjørnsen, 1992). Figure 1 below shows that the surroundings will

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[4] Albert Einstein said: "Everything should be as simple as possible, but not too simple"

always be present and influential irrespective of the perspective upheld by the actors.[5] Extending the system boundaries, by including the surroundings (going from a to b to c and finally to d), makes the system more complex. Figure 1d shows that industrial activity is limited by the industrial, social and ecological assumptions and frame conditions, but that these three assumptions and frame conditions are, except from the latter, dynamic elements which are altered through interaction.

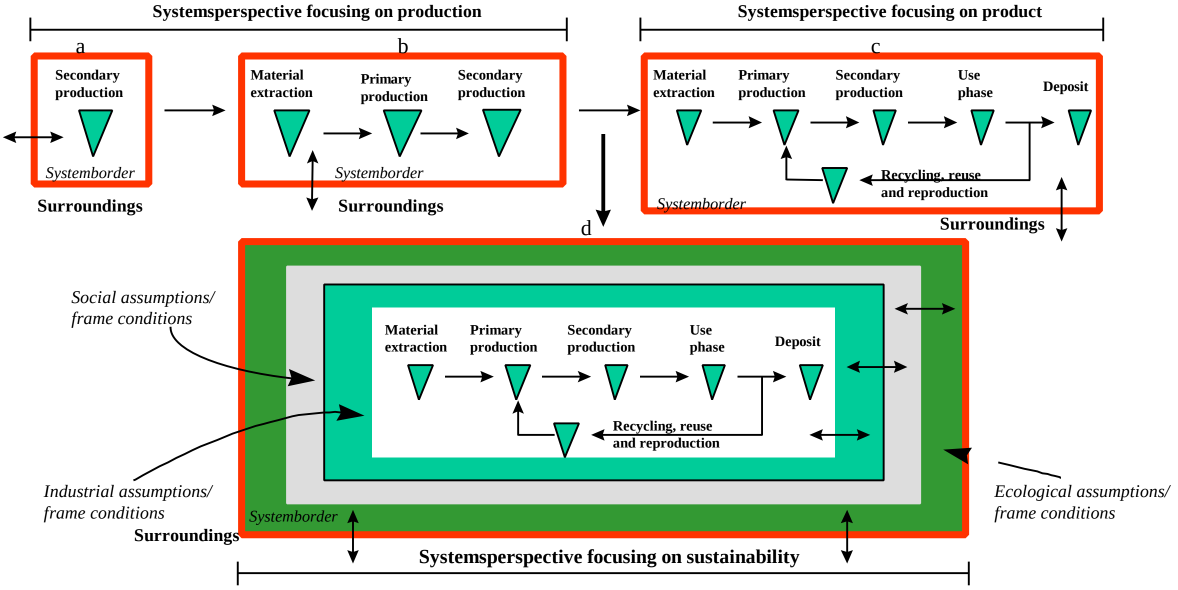

Figure 1: Different systems perspectives with defined systems and their surroundings

In this paper the interaction between the defined system and its surroundings will be our starting point for a systematic approach to the plastic packaging industry in Norway. We will present empirical data from this industry and discuss what should be important elements when assessing economic efficiency and environmental effectiveness.

Economic efficiency and environmental effectiveness

In everyday talk the word efficiency is often used recklessly. Usually it is not stated whether the efficiency is related to the environment, thermodynamics, technology, economy, cost or to the society in general. This paper is about economic efficiency and environmental effectiveness, and although these terms are defined in OECD (1997), they need some further clarification.

Historically, efficiency has been, and still is, the core of any technological and economic system (Quintanilla, 1998). Through the growing environmental consciousness trend, the term eco-efficiency is introduced as a working guideline for industrial companies (BCSD, 1993; Fussler and James, 1996). However, in "The NEXT Industrial Revolution" McDonough and Braungart (1998) argues that eco-efficiency does not go deep enough in handling environmental problems, because it operates within the same system as the problem was created. The article argues that the concept of eco-effectiveness should be the basis for the next industrial revolution[6]. These two terms, and the differences between them, hit the core of the concept of industrial ecology, which can be seen as a powerful concept towards this goal (Røine in prep., 1998). In the Norwegian research programme Productivity 2005 (P2005), a joint venture between academia and Norwegian manufacturing industry where industrial ecology is one of

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[5] An excellent example of this is the interaction between Norway and EU, with Norway being outside the European Union, but nevertheless has to see its activities in relation to what is happening inside EU, and visa versa.

[6] This discussion will focus on effectiveness and efficiency in general, and not on eco-effectiveness and eco-efficiency in particular

three strategic areas, one core activity will be to focus on eco-efficiency and eco-effectiveness in recovery systems and in design.

A general distinction between efficiency and effectiveness is obtained from Webster's Dictionary (1992).

Effectiveness = causing or capable of causing a desired or decisive result

Efficiency = the degree of effectiveness with which something is done

An example of the differences between these terms, is the present article. The finished product, the article, may be consistent with the initial objectives, and may thus contribute to a better understanding of extended producer responsibility. If so, it has an effect and the effectiveness may be high. The effectiveness is, thus, describing the relation between intended goals and actually obtained results[7]. However, it is difficult to predict the efficiency under which this article is produced. It may have taken years and consumed a lot of resources to finish. In that case the system has been effective, but not very efficient. On the contrary, in Nature the processes are very effective, but not necessarily efficient because the rate of reactions are often slow. In industrial processes the focus is on efficiency, emphasising high rates and throughputs. Talking from an environmental point of view, the effectiveness of these processes is often ignored. What the intended objectives really are, become crucial in this discussion.

Both effectiveness and efficiency are measures used to describe a system irrespective of how the system is defined. They differ from each other by effectiveness being an *extensive* measure and efficiency an *intensive* measure. Effectiveness is dependent on both quantity (volume, weight, energy and entropy) and quality (exergy and renewable/non-renewable). These may be added up to show the total amount of the property or resource in question. Hence, effectiveness can be related to an external point of reference. Quantitatively speaking, effectiveness traces the relation between input, output *and* the loss of a system, and, in more qualitatively and general terms, effectiveness concerns the relation between intended objectives and obtained results. In contrast, efficiency, being an intensive measure, cannot be added up. Efficiency refers to the property *per unit*, and is thereby dimensionless. Efficiency is thus *only* describing the system, and not the interaction between the system and its surroundings.

Figure 2 below describes in general terms a recovery system.

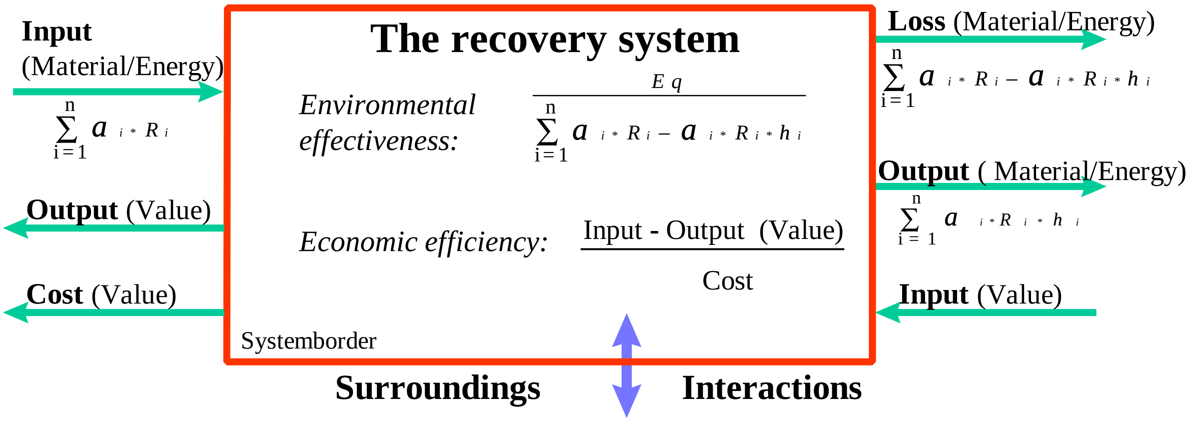

Figure 2: Countercurrent flows of material/energy and value with environmental effectiveness and economic efficiency

The flows of money and material/energy are countercurrent, given that input is always bigger than output. The value added is given by input minus output. In Figure 2 the inputs of material and energy

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[7] This description affect the relation between objectivity and subjectivity in research. Who states the intended goals, particularly from an environmental point of view?

are resources such as end products, raw/recycled materials, utilities, and energy[8]. The α in the formula is an index taking account whether the input is renewable ($\alpha > 1$), or non-renewable ($\alpha < 1$). The output is utilised and used for the purpose or function for which it was made, and thereby needs both quantitative and qualitative considerations. The output needs a market which demands quality.

The second law of thermodynamics states that every closed system will produce entropy, that is loss of quality. The loss from the recovery system is defined in Figure 2. The higher the efficiency, the lower the loss. The loss from one system is transferred to another system (the surroundings) that has to take care of or compensate for this loss. If the loss is positive, by having a positive effect on or increasing the value of the system it is entering, then there is no problem. This is the situation in natural ecosystems where waste (loss) from one process is feed (resource) for another, and equalise the no-waste idea in Nature. The problem occurs when the loss is negative, by having a negative effect on or decreasing the value of the other system, for instance through depletion of non-renewable resources or degradation of the quality of recipients. This negative loss has to be taken care of by Nature, by use of solar energy, since this is the only energy input to Earth. Solar energy gives potential increased value to renewable energy resources like wind, wave and water and to energy production in photo synthesis. If Nature is able to take care of the negative loss, then there is a sustainable situation. If not, the situation is unsustainable.

Environmental quality (Eq) is defined as the ability to preserve life in its natural context. As indicated in Figure 2, environmental effectiveness may be defined as the relation between environmental quality at any time and space and the loss of materials and energy from the defined system. In an environmental context, the goal of every human activity should be to limit the loss to a level that maintains the environmental quality.

The recovery system

The strategy of recovery deals with efficient and effective use of resources, and represents one alternative strategy to traditional waste disposal strategy.[9] Our task is therefore to analyse these strategies to see which one of these alternatives that are preferred from an economical and environmental perspective. We will show later the economic efficiency and environmental effectiveness by comparing one scenario with plastic recovery and one with plastic disposal. When analysing the recovery system of plastics in Norway, the following system is defined as shown in Figure 3[10]:

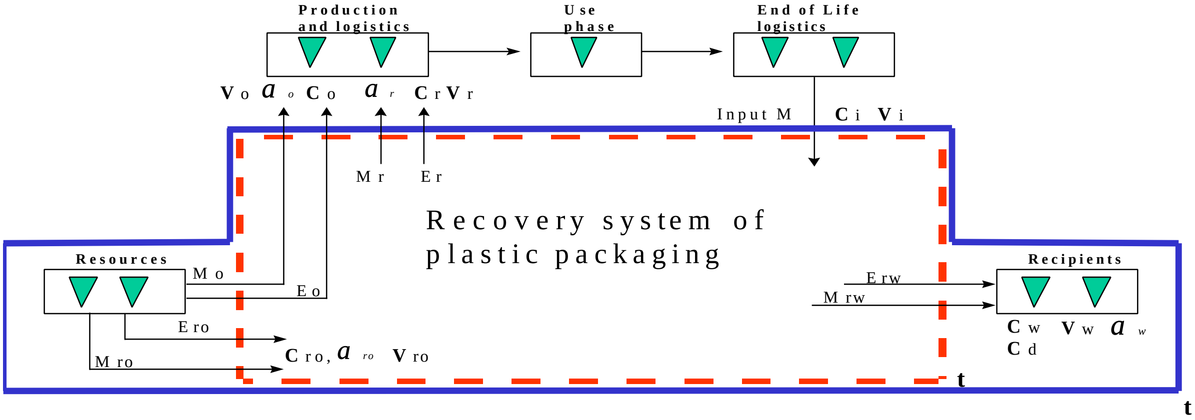

Figure 3: The defined plastic packaging system

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[8] The symbols are: R = resources, Eq = Environmental quality, η = efficiency, α = quality of the resource. A complete list of symbols is found at the end of the article.

[9] Resources are here both virgin materials, "waste" from use phase and recipients that compensate for negative effects of human activity.

[10] This system is valid for every recovery system

The defined recovery system is the inner dashed rectangle. The core activity is collection, sorting and actual recovery (see Figure 4). Input to the system is generated plastic packaging waste (M) and resources and utilities for actually carrying out the recovery process (Mro and Ero)[11]. The production and consumption of plastic are not included in the system. Output from the system is material (Mr) *and* energy from combustion (Er) that are traded in the market and are substituting virgin materials. Virgin materials and energy that are "competing" with the recycled products are denoted Mo and Eo respectively. Loss from the system, or unwanted output, is the materials and energy flows to the recipients, Mrw and Erw, respectively. The C's, V's and α's in Figure 2 and 3 are measures for cost, value and quality, respectively. This will be covered below. Cd is cost for disposal when this is the alternative strategy to recovery.

There are both an inner dashed rectangle and an outer non-dashed rectangle in Figure 3. Calculating economic efficiency, even at a social level, is often insufficient in an environmental context. Losses to recipients are often neglected or underestimated. The costs of resources are included, but the fact that the use of non-renewable resources are more costly, in an environmental sense, than the use of renewable resources, is often ignored. Hence, the outer non-dashed rectangle is important when calculating environmental effectiveness. In this case we have to include i) the loss from the system to the surroundings which can have a positive effect (increased Vw) or negative effect (decreased Vw) and ii) the use of non-renewable resources. This is shown by the outer non-dashed rostrum where both resources and recipients are included.

What is happening *within* the recovery system is shown in Figure 4. The thick lines are flows to the market (output and input) and the thinner lines are either input of resources to the system or loss from the system to the recipients.

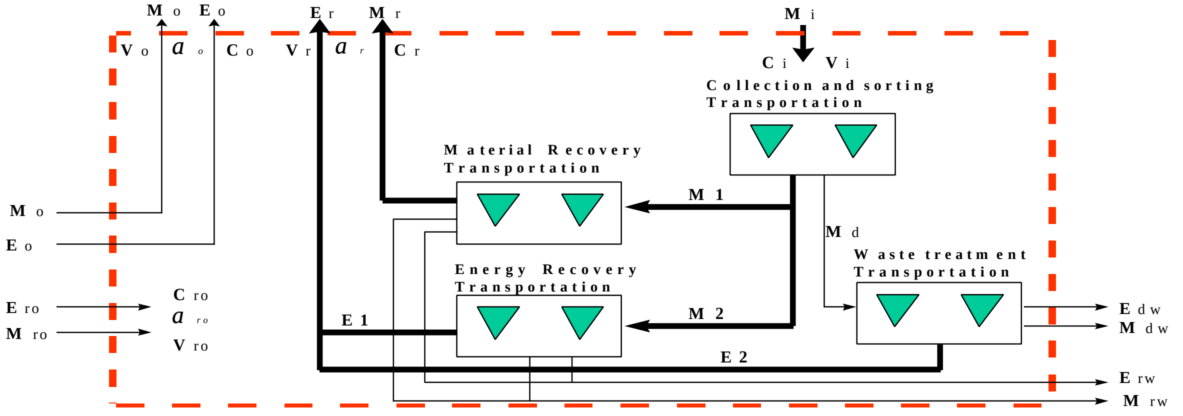

Figure 4: The flow within the defined system

In Figure 2 and 3 it is assumed that i) input of resources and utilities are needed to the recovery system, ii) recovered material is actually sold to the market iii) recovered and virgin material are competing in the same market iv) there is a distinction between renewable and non-renewable resources, and emissions to recipients may have both a positive and a negative effect

The recovery model presented raises a lot of questions. What is the optimal recovery ratio? What should be the relation between material and energy recovery? What is the economical and environmental impact of recovery? How robust is the recovery system to changes in for instance pricing of recipients and pricing of non-renewable resources? How does change in input M change the quality of output Mr? Given an increasing demand for quality in the market, what would be the most appropriate strategy: improve technology in recovery system, reduce input of M, or improve technology in the production phase? The plastic recovery system in Norway will be used to illuminate some of these questions.

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[11] The units for the abbreviations are: M (kg), E (J), C (US$/kg), α (an index, dimensionless), V (US$/kg).

Empirical studies - Plastic industry in Norway

Introduction

An agreement between The Norwegian Ministry of Environment and actors in the plastic packaging chain in Norway, the producers, was signed on 14th of September 1995. This agreement states that the producers should i) work for waste reduction and ii) build up a recovery system for plastic packaging with 50 % energy recovery and 30 % material recovery of all generated waste by the end of 1999. The producers established a "material company" (a PRO), Plastretur AS, 6th of November 1995, that should "develop, run, manage, monitor and organise collection and recovery of plastic packaging to meet the objectives of 50 % energy recovery and 30 % material recovery". Plastretur does not actively or directly contribute to the collection and recovery, but lets the market forces dominate and, instead, economically support those phases of the recovery system that is not functioning well.

The numbers in Figure 5 are from 1997. Out of 95.700 tons of packaging plastic waste[12], 50.644 tons are recovered, which is 52,9 % of total amount of plastic waste generated (Plastretur 1998). 14,8 % was material recovery, while 38,1 % was energy recovery[13]. The producers paid 5,02 million US$ a year to Plastretur in order to run the recovery system, which means there is a further potential to increase this payment from the producers by getting the "free-riders" involved.[14]. Plastretur is subsidising recovery companies and collectors/sorters with approximately 3.02 million US$. In addition there are expenditures to information, administration and staff.

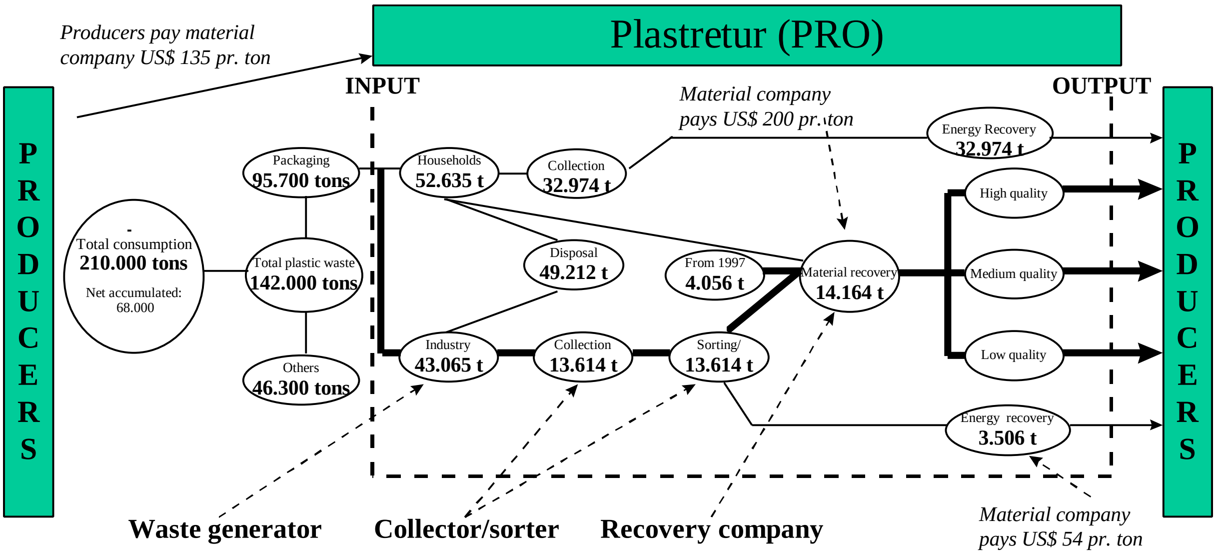

Figure 5: The flow of plastic in Norway, 1997

The plastic packaging waste is categorised in household waste (55 %) and industrial (production) waste (45 %). The industrial part (43.065 tons) is mainly from agriculture, aquaculture and industrial production itself. Since it is not possible to grasp all the elements in the total system, it is focused on material recovery, indicated by the thicker lines in Figure 5, with *one waste producing company (Hakon-group), one collection and sorting company (Franzefoss Gjenvinning), one material recovery company (Folldal Gjenvinning) and one producer of products using recycled materials (Rosenlew).*[15]

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[12] The consumption of plastics in Norway is 210.000 tons per year. 68.000 tons are net accumulated, which gives 142.000 tons of plastic waste a year. Out of this, 95.700 tons is plastic packaging waste (Plastretur 1998.

[13] 7 % of all household waste are calculated to be plastics, and in municipalities with energy recovery this is credited the recovery of plastics in Norway.

[14] The producers pay, pr. 20/10 1998, US$ 0,14 to Plastretur pr. kilogram plastic sold to the market.

[15] It is assumed that these are average firms in Norway, a view supported by Plastretur.

The different actors in the recovery chain

Plastretur is playing an active role in the recovery system, without actually participating in the actual recovery. Today the recovery system is established for the industrial part, and pilot systems for households in certain municipalities are established. Plastretur has signed agreements with private companies all over Norway that collect/sort and recover plastic packaging.[16] Through this agreement these companies are obliged to collect/sort and recover packaging waste if this is requested by the waste generators. Plastretur pays these companies, depending on the quality of the plastic and whether material or energy are recovered (see Figure 5). The task of Plastretur is to stimulate the recovery system in such a way that the objectives of recovery are met.

The waste generator, Hakon-group, started last August a project on collecting and sorting plastic bags which the customers bring back to the stores[17]. These plastic bags are gathered up with other plastic packaging waste from their activity. This is sent to Folldal Gjenvinning on "back-load", which reduces the actual transportation cost dramatically. For a sorted fraction of good quality Hakon-group is paid 135 US$/ton. Instead of paying tax for disposal, the company gets paid for the valuable waste it possesses. Another motivation, Hakon-group argues, is that it will be regarded as an environmental conscious company, and will also benefit economically from this in the long run. Environmentally speaking, Hakon-group contributes to reduction of extraction of non-renewable resources and to reduction of the disposal needs, since plastic is quite voluminous. Hakon-group has no measures on volume, transportation costs, energy/material consumption related to this new activity. They do not have a number of the potential collection of used plastic bags pr. year either.

Hakon group sends their plastic waste directly to the recovery company. In most cases, however, a collecting and sorting company links the waste generator and recovery company. Franzefoss Gjenvinning is such a company. This company collects 300 tons of plastic a year for material recovery and 10-15 tons for energy recovery, mainly from aquaculture. The agreement with Plastretur states that Franzefoss Gjenvinning shall collect plastic packaging waste for free 4 times a year. If the waste generators want more frequent collection, they have to pay for this, and the price is dependent on the market. Depending on the quality of the plastic, Franzefoss Gjenvinning gets from Plastretur approximately 200 US$/ton sent to material recovery and 54 US$ sent to energy recovery. This balance the transportation and labour costs. They neither earn nor lose money on this, and their owners regard and accept this as a non-profit activity (Berntsen, 1998). The motivation for doing this is 1) a future economic potential as the amount of collected material will increase, and 2) that the company contribute to a positive development for the society (Berntsen, 1998)

Folldal Gjenvinning is a material recovery company producing granulated plastics from non-rigid plastic waste. The input to their production is from a wide region in Norway, in addition to some import from Sweden, mainly provided by collecting and sorting companies like Franzefoss Gjenvinning. Production is approximately 400 tons/month. The price of their final product is dependent on the quality: For high quality the price is about 70 % of virgin material, for middle quality it is about 60 % of virgin material and for low quality it is about 50 % of virgin material.[18] The production cost is approximately 70 US$ per ton product. In the process approximately 30 % of input is lost due to pollution in the input and spill from the production. Folldal Gjenvinning gets between 200 and 260 US$ per ton in subsidies from Plastretur, and they pay between 67 and 135 US$ per ton for the input, both dependant on the quality. The gross turnover is 3.24 million US$, resulting in a surplus of 70.000 US$ a year. There is lack of raw materials, and Folldal Gjenvinning thinks there is potential in Norway to handle all the waste that is the goal by the end of 1999.

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[16] In total about 90 companies

[17] Hakon-group is a big Norwegian general store with a 20 % share of the Norwegian market and with some activities abroad

[18] The price of virgin plastic material is 807 US$ (Riksen, 1998)

The producer of plastic bags, Rosenlew, now runs a project on plastic bags consisting of 60 % recycled material from Folldal Gjenvinning, 30 % site waste and 10 % virgin material. This change in the production input has resulted in increase in the thickness of the plastic bags with 10 % in order to obtain the same quality as with entirely virgin materials. The change has also resulted in more stops in the production due to relatively more polluted input than when only virgin materials are used. Any estimates of the costs due to this is not given by Rosenlew (Riksen 1998). However, the consumption of energy for production is the same and the costs are reduced because of cheaper raw materials. Riksen (1998) says, however, that it is technological advisable to use virgin materials only.

Discussion

Introduction

The objective of this paper is to discuss economic efficiency and environmental effectiveness in plastic industry in Norway. To some it may seem to be unnecessary to distinguish between these terms since economic efficiency in macro-economics is, ideally, including the environmental consequences of activities at company level. However, getting the prices right are not sufficient. The *scale* of the production and activity should be taken into account, and in this perspective the distinction between the two terms seems legitimate (Daly,1996). The term "effectiveness" raises the question of intended objectives, and three main objectives for the recovery system can be pulled out of Figure 3:

1. An economic efficient system of recycled material and energy that is demanded in the market and that is competing with and substituting virgin materials.
2. A minimum extraction of non-renewable resources that are brought into the recovery system or the regular production system.
3. A minimum loss of material and energy that may have negative effect on the recipients.

The first paragraph deals with economic efficiency. The two latter concerns environmental effectiveness and the relation between political objectives and scientific, for instance thermodynamic, arguments of what might be a correct level of recovery. Since the robustness of the recipients differ in both space and time, it is impossible to tell in general what an ideal recovery ratio should be.

Economic efficiency

OECD defines economic efficiency in macro-economic terms. Including all social and environmental effects of an activity implies of course the problem of how to value these effects. What is for instance the time and space perspective in such a valuation? One way of "avoiding" part of this problem may be to compare the recovery strategy with an alternative strategy: Disposal. By comparing these two strategies the same "valuing failure" is made in both cases, and may, to a limited extent, neutralise each other. The strategy that results in the lowest costs to society should be preferred.

The economic efficiency for a system is the ratio between the value added throughout the system and the costs spent to add this value. Mathematically, based on Figure 3 and Figure 6, economic efficiency can be defined as:

$$\eta_{econ}=\frac{Gain}{Costs}=\frac{Vom*Mr+Voe*Er+Vr*Mr+Voe*Er-Vi*M}{Cr*(Mr+Er)+\alpha ro*Cro*(Mro+Ero)+\alpha w*Cw*(Mrw+Erw)-Cd*(Mr+Er)}$$

This formula takes into account that i) costs of processing virgin materials to plastic materials of a certain quality (Vom*Mr+Voe*Er) and ii) disposal costs (Cd(Mr+Er)) are saved when recovery is the preferred strategy[19]. Further, Vr*Mr+Voe*Er is the actual value of the recovered product in the market, Vi*M is the cost of input to the recovery system, Cr (Mr+Er) is the cost of the actual recovery[20], αro*Cro(Mro+Ero) is the cost of utilities, energy, materials and extraction of virgin materials for carrying out the recovery[21], αw*Cw(Mw+Ew) is the cost of disposal from the recovery process[22] and Cd*M is the avoided disposal costs since recovery is chosen as strategy instead of disposal. Factors like employment, growth and competitiveness are not included here.

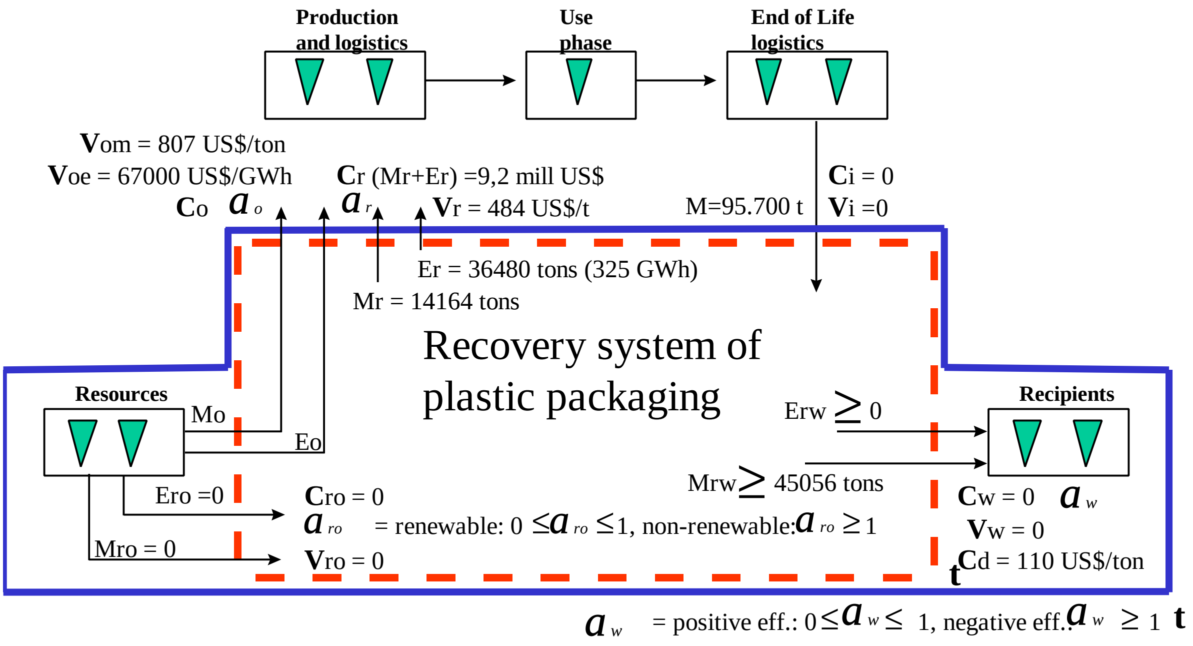

Figure 6: The recovery system with numbers

Figure 6 shows the recovery system with numbers. The terms Voe, Vom, Mr, Er, Vr, M, Vi, Cr and Cd are known. Since it has been hard to find data on the others, it is difficult to obtain an exact result for this. However, a rough calculation is made.

$$h_{\text{econ}}=\frac{807\ \text{US\$/ton}*14164\text{ton}+67000\ \text{US\$/GWh}*325\ \text{GWh}+484\ \text{US\$/ton}*14164\ \text{tons}+67000\ \text{US\$/ton}*325\ \text{GW}h-0}{9{,}2\ \text{mill US\$}+0+0-110\ \text{US\$/ton}*50644\text{tons}}=17$$

Based on these numbers, the economic efficiency in the recovery system is 17. In reality, the costs are higher, mainly because no empirical data has been available for costs of resources and of recipients, and these elements are set to zero. This is not a correct assumption, but the denominator in the equation should be equal or bigger than the numerator if the recovery should not be carried out, which means that the costs of these resources and recipients should at least be 56 mill US$. This is for instance 10 times higher than the disposal costs (Cd(Mr+Er)).

If the benefits from i) no extraction of new raw materials due to recovery and ii) disposal costs are ignored, the economic efficiency will be:

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[19] Vo is the value of virgin material. It is multiplied with the (Mr+Er) because this is the amount that is substituting the virgin material with value Vo. Further Cd is the deposit costs if input M was deposited instead of recovered.

[20] See Figure 4 for details

[21] The αro in the formula is an index taking account whether the input (resource) is non-renewable (α>1), or renewable (α<1).

[22] The αw in the formula is an index taking account whether the input has a positive (α>1), or negative (α<1) effect on the surroundings

$$h_{econ} = \frac{484\ \text{US\$}/\text{ton} * 14164\ \text{tons} + 67000\ \text{US\$}/\text{ton} * 325\ \text{GW}h - 0}{9{,}2\ \text{mill US\$} + 0 + 0} = 3$$

However, it seems correct to include these benefits because resources are actually conserved, and have thereby a value for future generations. As for disposal, it can be argued that the environmental quality of the recipients benefits when recovery is carried out, and this is not directly included in the price of input M, but is rather a political, non-market value.

When preferring disposal instead of recovery as the strategy, the gain is what is avoided in running the recovery system (Cr*(Mr+Er)). Costs are for disposal (Cd*(Mr+Er), and the extraction of raw materials (Vom*Mr+Voe*Er) In total the economic efficiency is then estimated to be

$$h_{econ} = \frac{9{,}2\ \text{mill US\$}}{110\ \text{US\$}/\text{ton} * 50644\ \text{tons} + 807\ \text{US\$}/\text{ton} * 14164\ \text{ton} + 67000\ \text{US\$}/\text{GWh} * 325\ \text{GWh}} = 0{,}24$$

Although these are rather rough estimates, this indicates a direction towards that the plastic recovery in Norway is an economic efficient way of handling packaging waste compared to disposal. A Norwegian study done by Bruvoll (1998) concludes that recovery of plastic is not advisable because of high socio-economic costs. This study is disproved by another Norwegian study by Hanssen (1998) stating that the assumptions of Bruvoll are highly debatable and questionable. Hanssen argues that the costs saved when avoiding disposal and extraction of new, particularly non-renewable, raw materials must be included in the account. Besides, Bruvoll highly prices the time spent in every household for collecting and sorting plastic waste (2 minutes pr. day), and this is a substantial contributor to her conclusion that plastic recovery is not economical advisable. These two studies and a third report evaluating the covenants in Norway (SFT, 1998) all concludes, however, that there is lack of detailed statistical data on material flows and transportation costs in Norway, making calculation of economic efficiency difficult and inaccurate.

Processing recovered plastic material is just a postponement of disposal, and then to a much higher cost, *if* the recovered material is not realised in the market. The recovered products compete with corresponding products made from virgin materials. This means that the *quality* of these two products, labelled αo and αr in Figure 3, are essential.[23] If the degree of recovery in the entire recovery system is increased, the quality of the recovered product will decrease due to the fact that the qualitatively best and most available material is recovered first. The costs of collection increases with higher degree of recovery because of decreased availability.[24] On the contrary, if recovered material to a larger extent substitute virgin materials in the market (the degree of recovery increase), the quality of recovered product must increase to meet the requirements in the market. Ideally, with 99,9 % recovery, the quality of virgin and recovered material should be equal. This is extremely energy demanding, due to the second law of thermodynamics and is thus surely neither economically nor environmentally sound. The conclusion on these arguments is that increased degree of recovery results in higher quality demand of recovered products in the market, while the quality of the output from the recovery system is actually decreasing. It is here assumed that the consumers demand the same quality of plastic, independent on whether the material is virgin or recovered. Hence, there is an optimum of economic efficiency for recovery as shown in Figure 6 below. Given a constant input of generated plastic waste, the economic

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[23] Rosenlew produces plastic bags with 60 % recovered material, 30 % spill and 10 % virgin material. This brings about more frequently production stops, due to the lower quality of recovered material, but not more seriously than that this concept works. The quality of repetitively recovered material is decreasing, and plastic "molecules" cannot be recovered more than 5-6 times to maintain a minimum quality. The plastic is then energy recovered.

[24] The reason to this is that the concentration of virgin materials are much higher (for instance oil in reservoir) than the concentration of generated plastic packaging waste (for instance plastic bags in every home in Norway).

efficiency will follow the law of diminishing returns, that there is a linear increase of gain while the costs are exponential increasing when increasing the degree of recovery.

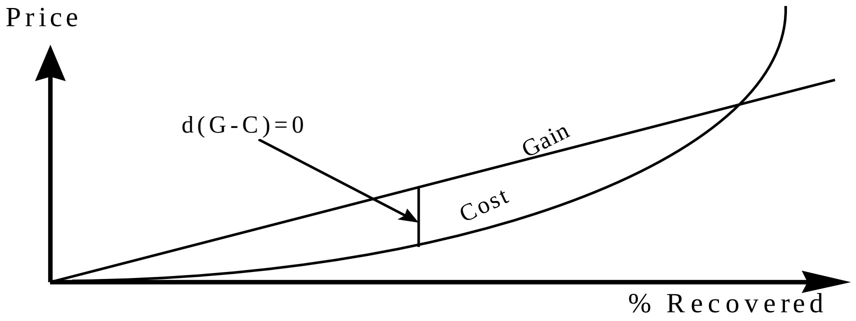

Figure 6: Optimal economic efficiency is obtain at d(G-C)=0

On this background, the ratio between material and energy recovery, is very much determined by the economic efficiency of material recovery, because there is no quality demands in the market as such for energy recovery (Lynne, 1998).

An appropriateness and robustness of the recovery system seem very important to develop in order to obtain an effective and efficient system. By appropriateness is meant that stable markets need to be established for recovered products and that recovered products are qualitatively satisfying a (potential) demand in the market. In an environmental aspect it is preferable that recovered material does not come in addition to existing use of virgin material, but actually *substitutes* virgin material, both in existing products and in new products. This is about sufficiency. As important as establishing recovery system is therefore to focus on i) waste minimisation by work done in the design phase, and ii) technological innovation and diffusion in order to design products that use recovered materials. In Norway quite a lot work is done, often initiated by Plastretur, on encouraging producers of plastic products, or producers of functions that can use recovered plastic material, to be aware of this potential. By robustness is meant the ability to obtain stability and flexibility in the recovery system in relation to the prices of resources and recipients, and to changing demands in the market. It seems that the role of Plastretur has been very important to innovate and diffuse the technology and behaviour that is needed to obtain an effective system.

Environmental effectiveness

Environmental effectiveness is, by OECD (1997) defined as "improvements in environmental quality, health risk reduction and resource efficiency". The keyword is improvements, but it does not tell us what the improvements should be related to, which indeed is important when dealing with effectiveness. What is the defined system? And what is environmental quality and resource efficiency? The latter is used in defining effectiveness indicating an incorrect mix of efficiency and effectiveness.

The assumption that monetary cost reflects the environmental cost is not necessarily true. The main reason for this is the different time perspectives taken in an economic and an environmental context, respectively. Another reason, which is derived from the first, is the lack of qualitatively distinction between renewable and non-renewable and the lack of regarding the quantitative and qualitative loss of material and energy to recipients.

The main problem concerning the time perspective is that the time constant for the two different terms are strongly different. When calculating economic efficiency the time constant and time perspective is fairly short, due to short payback - time. The environmental effects and feedback are very difficult to grasp because they may occur in 20, 50 or 100 years from now. Even if there is more or less clear evidence on environmental change and degradation, the inherent uncertainty about the future will make monetary valuation of environmental effects difficult. The problem of discounting the future is counteracting the objective of non-degraded environmental quality in the future. In this sense the payback time could be one interesting indicator. Besides, valuing is dependent on for instance cultural, social and ethical considerations which makes it almost impossible to agree upon the values. The politicians are perhaps, being representatives of the population, appropriate to decide this. Decision-making in an environmental sense has to be long term oriented.

As mentioned in the beginning of this paper, the prices of non-renewable resources and of recipients are lower than they should be. The environmental effectiveness may decrease while the economic efficiency is increasing. The price of non-renewable resources and recipients are kept constant, while the stocks of non-renewable resources and the environmental quality is decreasing. This phenomena is to a little extent taken into account in pricing the externalities today. Hence, environmental effectiveness is important to consider in coherence with economic efficiency. This is shown in Figure 7. An interesting question, besides the question of where on the time scale we are now, is *when* the society will react on the environmental degradation by increasing the value of non-renewable resources and recipients.

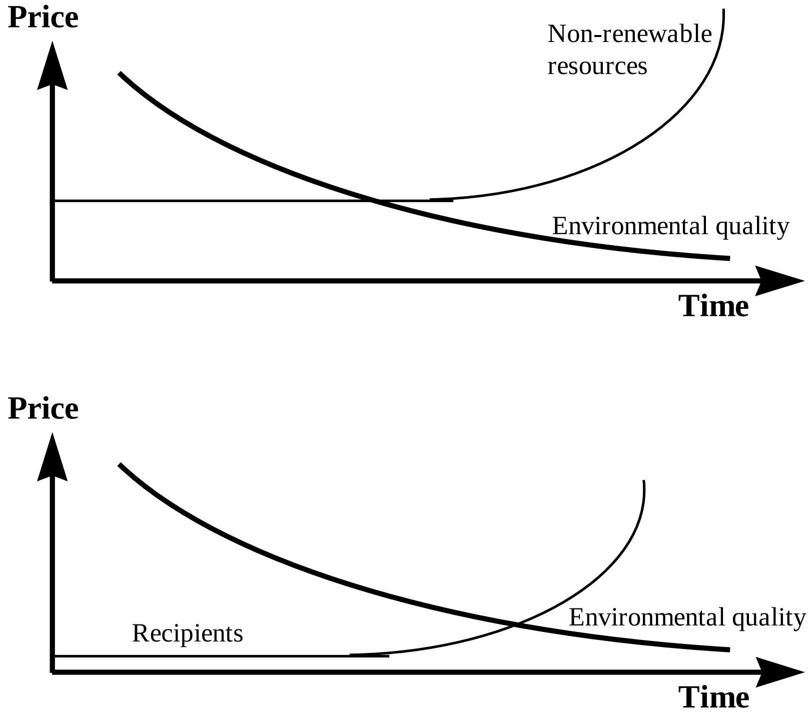

Figure 7: The price of non-renewable resources and recipients being independent of environmental quality

Environmental effectiveness should include the extraction of non-renewable resources and the loss of material and energy that have negative effect on the recipients. As shown in Figure 2 an equation of environmental effectiveness could be:

$$\text{Environmental effectiveness} = \frac{Eq}{\sum_{i=1}^{n} a\,i * R\,i(1 - h\,i)}$$

The numerator (Eq) is environmental quality, which is both time- and space dependent. The equation relates the loss from the system to the surroundings and the recipients. A high environmental quality can tolerate relatively greater loss from the system. The loss is an extensive measure (Ri*(1-ηi), and αi is a qualitative measure. An appropriate tool for measuring loss may be exergy analyses. By including "loss" in this equation, the focus is also on conservation of nature, materials and energy instead of consumption. The link to natural processes is obvious. These processes are driven in order to minimise the entropy production (by making ΔS as small as possible), independent on the time spent to do so. The least path of resistance is chosen. This is in a way contradictory to the steadily lower payback-time in industry, which contributes to make thing more efficient, but not necessarily more effective.

With these more general comments as background, the practical experiences with environmental effectiveness in recovery system for plastic in Norway will be discussed. In general, there is lack of thorough environmental studies that discuss this. As mentioned above, the agreement between Ministry of Environment and the producers states that i) the amount of waste shall be reduced and ii) 80 % of the plastic packaging waste shall be recovered by the end of 1999. The indicators used to evaluate this is the actual recovery ratio and to some degree the total amount of disposal. By using only these two indicators some important elements of environmental effectiveness are lacking.

The reduced extraction of raw materials, and then particularly non-renewable resources should be evaluated. Further the loss to recipients, both quantitatively and qualitatively should also be traced. Third, transportation costs and impacts in total is a natural part of such study.

It also seems necessary to discuss the actual objectives stated in the agreement. These are political objectives agreed upon by government and producers. The first objective relates to the total amount of waste in Norway, this may be a good indicator of the environmental effectiveness of the system. The second objective, however, are in a sense testable, but do not really trace the effect of a recovery system to its natural surroundings. On what basis is the objective of 80 % recovery determined?

The life cycle perspective is very important. Establishing recovery systems is essential, but is in fact more a reactive and end-of-pipe solution than a proactive prevention strategy. Plastretur is aware of this argument, and has done some projects on it as well, but regarded from a systems or life cycle perspective, this should be an even more dominant part of the work when concerning environmental effectiveness. Without focusing in this, it is a sub-optimal system.

Conclusion

This paper has, through a theoretical discussion of efficiency and effectiveness, presented a model for a recovery system. The plastic packaging recovery system in Norway is described, and despite the lack of empirical data, the economic efficiency for the system is shown and discussed, based on this model. A discussion has also been carried out on environmental effectiveness showing that the Norwegian plastic recovery system has to focus to a larger extend on the use of non-renewable resources and on the effects of loss of energy and materials to the recipients. In other words, it is strongly needed to analyse what is the optimum recovery ratio in an economic and environmental context. A positive element in the Norwegian system is, however, the focus on developing a market for the recovered materials.

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Appendix 1

List of symbols

Mro: Input of material to recycling system (ton)

Ero: Input of energy to recycling system (GWh)

Mo: Input of material to production and logistics (ton)

Eo: Input of energy to production and logistics (GWh)

Cro: Cost of input of material and energy to recovery system (US$/ton)

αro: Quality of input of material and energy to recovery system

Vro: Value of input of material and energy to recovery system (US$/ton)

Vo: Value of material and energy to production and logistics (US$/ton)

αo: Quality of material and energy to production and logistics

Co: Cost of input of material and energy to production and logistics (US$/ton)

αr: Quality of recycled material and energy to production and logistics

Cr: Cost of recycled material and energy to production and logistics (US$/ton)

Vr: Value of recycled material and energy to production and logistics (US$/ton)

Mi: Input of material to recovery system (ton)

Ci: Cost of material to recovery system (US$/ton)

Vi: Value of material to recovery system (US$/ton)

Erw: Energy from material and energy recovery to disposal or recipients (GWh)

Mrw: Material from material and energy recovery to disposal or recipients (ton)

αw: Quality of waste from recovery system to disposal or recipients

Cw: Cost of waste from recovery system to disposal or recipients (US$/ton)

Cd: Cost of disposal when this is the alternative strategy to recovery (US$/ton)

Vw: Value of recipients or disposal(US$/ton)

Mr: Material from recovery system to new production (ton)

Er: Energy from recovery to new production (GWh)

M1: Input to material recovery (ton)

M2: Input to energy recovery (ton)

Md: Input to waste management (ton)

E1: Energy from energy recovery (GWh)

E2: Energy recovery from waste treatment (GWh)

Appendix 2

Details in calculation of economic efficiency

It is assumed that Vo for materials is 807 US$/ton[25] and 67.000 US$/GWh for energy[26] , Mr is 14164 tons (Plastretur 1998)[27], Er is 36.480 tons (325 GWh) (Plastretur 1998)[28], Vr is 484 US$/ton[29] and M is 95.700 tons (Plastretur 1998). Vi (input to the system) is assumed to be zero. The main reason for this is that plastic waste as raw material and input to the recovery system, has both a positive, negative and zero value in the market.[30] Another reason is that the price of the plastic *in the market* would have been zero if the recovery system did not exist. The cost of disposal (Cd) if the material is not recovered is 110 US$/ton, based on average price on landfills (Berntsen 1998). [31]

Cr (Mr+Er) is estimated to be 9,2 mill US$ pr year.[32] The costs are the turnover of Plastretur (1998), the net costs (total costs minus subsidies) for the two most important actors within the recovery system

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[25] This is the price of virgin plastic material that is competing with recovered product. Given by Snorre Riksen, Executive general manager, Rosenlew. 20/10 1998.

[26] It is assumed a price of electricity in Norway of 0,067 US$/kWh

[27] See Figure 5

[28] This is equivalent to 8900 kWh/ton * 36480 tons = 325 GWh. See Figure 5

[29] As an average, the price of recovered material is 60 % of virgin material. Given by Snorre Riksen, Executive general manager, Rosenlew. 20/10 1998.

[30] For instance Hakon-group gets paid while some companies in aquaculture pay themselves.

[31] In one county in Norway the cost of disposal *is* very high because there exists a recovery system which is encouraged to use.

[32] 5,02 mill US$ is the turnover. For materials: 14164 tons*270 US$ = 3,82 mill US$. For energy (transportation) 100 US$/ton*3506 tons = 350600. All together: 9,2 mill US$.

for material, Franzefoss Gjenvinning and Folldal Gjenvinning and the net costs for energy recovery. Franzefoss Gjenvinning assumes that average transportation distances for its products is 200 kilometres[33], which gives an average transportation cost of 100 US$/ton. This is in total covered by the subsidies from Plastretur (Berntsen 1998).[34] Folldal Gjenvinning has expenditures in addition to what is subsidised of 270 US$/ton (Rogstad 1998). Net costs for energy recovery is based on the industrial fraction in Figure 5, assuming average transportation costs of 100 US$, which equals 350.600 US$.

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[33] This estimate is quite high. Hanssen (1998) assumes average transportation distances at 40 km/ton which reduces the costs to 1/5 (50 % recovery). On the other hand, Bruvoll (1997) argues that the average transportation costs is 70-80 times higher than the numbers used by Hanssen (1998). Hanssen argues that the transportation costs in a recovery system is not significantly higher than in a disposal system.

[34] However, the collection system is to a large degree based on back-load transportation, which means that the actual additional costs for collecting plastic packaging waste is not as much as 100 US$/ton. The transportation costs will increase with increasing degree of recovery.