Annegrete Bruvoll

The Costs of Alternative Policies for Paper and Plastic Waste

Statistisk sentralbyrå • Statistics Norway
Oslo–Kongsvinger

Rapporter	I denne serien publiseres statistiske analyser, metode- og modellbeskrivelser fra de enkelte forsknings- og statistikkområder. Også resultater av ulike enkeltundersøkelser publiseres her, oftest med utfyllende kommentarer og analyser.
Reports	This series contains statistical analyses and method and model descriptions from the different research and statistics areas. Results of various single surveys are also published here, usually with supplementary comments and analyses.

ISBN 82-537-4478-1
ISSN 0806-2056

Emnegruppe
01.05 Avfall

Emneord
Avfallsavgifter
Avfallsgjennvinning
Avfallshåndtering
Forbrenning
Deponering
Papiravfall
Plastavfall

Design: Enzo Finger Design
Trykk: Statistisk sentralbyrå

Standardtegn i tabeller	Symbols in tables	Symbol
Tall kan ikke forekomme	Category not applicable	.
Oppgave mangler	Data not available	..
Oppgave mangler foreløpig	Data not yet available	...
Tall kan ikke offentliggjøres	Not for publication	:
Null	Nil	-
Mindre enn 0,5 av den brukte enheten	Less than 0.5 of unit employed	0
Mindre enn 0,05 av den brukte enheten	Less than 0.05 of unit employed	0,0
Foreløpige tall	Provisional or preliminary figure	*
Brudd i den loddrette serien	Break in the homogeneity of a vertical series	—
Brudd i den vannrette serien	Break in the homogeneity of a horizontal series	|
Rettet siden forrige utgave	Revised since the previous issue	r

Abstract

Annegrete Bruvoll

The Costs of Alternative Policies for Paper and Plastic Waste

Reports 98/2 • Statistics Norway 1998

After decades with landfill and incineration as the most common waste treatment methods, the current main waste policy strategy has changed toward recycling. Also, most governments declare that source reduction, to reduce the generation of waste, is the best choice, while in practice few steps have been taken in this direction. In order to improve the understanding of optimal policies for paper and plastic waste reductions we compare the costs of the four alternatives recycling, incineration, landfill based on a combination of US and Norwegian data, and source reduction implemented by a tax on material inputs.

This study supports the ranking of source reduction as the most efficient alternative. Price incentives directed towards reducing material use and waste is more efficient than rectifying the damages of already generated waste. While a tax on waste generating materials actually involves net benefits, all the other alternatives involve net costs.

Furthermore, in an environmental as well as economic perspective the heavy emphasis on recycling may well be misleading, as the environmental and the economic costs exceed the costs of incineration and landfill in most cases. Higher environmental and economic transport costs from recycling more than outweigh the emission costs and conventional costs from incineration and landfill plants in our analysis. Recycling is the least costly alternative for commercial paper waste, due to relatively low pickup costs and high commercial value of recycled paper.

Keywords: Incineration, landfill, paper waste, plastic waste, recycling, waste taxes.

Acknowledgement: Funded by The Research Council of Norway.

Contents

1. Introduction

The «waste hierarchy» ranges waste minimization as the best waste treatment alternative, then recycling, incineration and landfill as the last-ranking alternative. This hierarchy is the generally accepted golden rule within waste policy making. The stated main strategy in Norway and EU is source reduction, based on the hypothesis that it is better to prevent the generation of waste than to rectify damages. However, the in practice dominating policy is mandated recycling, while waste minimization and source reduction, strictly defined as reductions in the amount of materials used, are less subject to political priority (see e.g. Bernstein 1993, Brisson 1993 or Bruvoll and Ibenholt 1995a and 1995b).

The stated Norwegian policy also claims that the choices between treatment alternatives must be cost efficient. The implicit argument in the current dominating political trend is that for all private and social costs, recycling is initially less costly than incineration, and incineration less costly than landfill. This might be correct for many materials, but the literature offers no evidence for this general ranking (Goddard, 1995). Rather, the general basis for evaluating the cost efficient choices is deficient. Particularly, judging whether the emphasis on recycling programs is cost efficient is frequently pointed out to be hampered by poor, incomplete or inconsistent data. Despite the lack of supporting analyses, the politically set recycling targets on packaging waste in Europe are generally above 60 per cent (Brisson 1993).

To contribute to a better understanding of the costs and benefits of different treatment options, we endeavor in this paper to get a comprehensive picture by integrating results from different cost studies. We study plastic and paper waste specifically. First we analyze the marginal economic and environmental consequences for source reduction implemented by a tax on packaging waste raw materials, and then the recycling, incineration and landfill costs.

Due to the lack of relevant Norwegian data, the analysis relies heavily on American data. The cost levels might differ from Norwegian costs. However, we are concerned with the relative ranking in the hierarchy. The relative difference between recycling, incineration and landfill costs in US and Norway might differ. We have not studied the detailed differences between Tellus' data and Norwegian conditions to argue for a certain bias, but hopefully this paper can lead to a discussion of the data and improved estimates in the second hand.

The main source of data is Tellus' disposal cost fee study, Tellus (1991), which provides data on conventional collection and processing costs and air emissions from transport. The air emissions are further evaluated according to a range of different sources of damage estimates. The main source of air emissions from incinerators and landfills is ECON (1995).

The estimates on environmental costs of collection and treatment of emissions vary highly between different studies and estimation methods. To reveal the uncertainty, we have estimated intervals based on the lowest and the highest cost estimates, in addition to chosen best estimates (for explanation of the chosen values, see Bruvoll and Wiig 1996). Also, it is generally not possible to measure the value of environmental externalities objectively. In lack of morally sound and objectively reliable prices on environmental commodities, the decision-makers should be provided with physical measures describing the consequences of alternative policies. Therefore, in case new and better estimates are developed or if the reader is critical to the values used, we also present all the underlying physical measures. Then the estimates in this analysis can be critically evaluated and adjusted according to new information and diverging preferences.

We start out with summarizing the results in section 2. In the sections 3 to 6 we discuss the details behind the cost estimates for source reduction, recycling, incineration and landfill respectively. Section 7 concludes. In Appendix the underlying data is presented.

2. Main results

This study shows that the ranking of source reduction on the top of waste hierarchy is efficient for paper and plastic waste. The overall conclusion is that the tax alternative offers net benefits, while the other policy forms recycling, incineration and landfill involve net costs. Thus price incentives directed towards reducing material use and waste is more efficient than rectifying the damages of already generated waste. However, the thumb rule of ranking of recycling over incineration and landfill has not proven to be efficient.

Recycling is the best alternative after source reduction for *commercial paper*. Due to the high conventional and environmental collection costs, our data shows that recycling of *household paper* and *plastic* waste is more costly than landfill and incineration. This conclusion is supported by several general waste cost studies. A recent analysis by Bystrøm and Lønnstedt (1997) on paper waste uses a life cycle approach to compare the waste treatment options. They conclude that there is no evidence that increased recycling based on pulp is environmental friendly, compared to e.g. energy recovery as a substitute for fossil fuels. REFORSK (1993) evaluates particularly the aspect of whether the incinerated material substitutes other energy sources, and concludes that if incineration competes with fossil fuels, incineration can be a better alternative than recycling.

The conclusions are highly generalized «on average results», based on aggregated data. For disaggregated waste fractions, individual results may deviate from our main conclusions. The collection costs, e.g., amount to about half the costs for recycled paper and 80-90 per cent for recycled plastics. These costs are clearly higher than in less populated areas and lower in cities or localities nearby treatment facilities. Also, the total net costs vary between different paper and plastic products. If the distance to a recycling facility is low compared to the alternative incinerator or landfill, recycling can be the most efficient treatment alternative for other wastes than commercial paper waste. Accordingly, recycling of commercial paper waste is not always preferable to the other treatment methods. The assumptions of recycling collection methods and incineration and landfill rinsing technology are also crucial to the conclusions.

2.1. Source reduction

The immediate result of a waste reducing material tax is a reduction in packaging waste. However, this reduction is small compared to the reductions in paper and plastic material inputs and other material inputs, which inevitably end up as waste and emissions at a later point. Furthermore, the macroeconomic model used reveals that air emissions from economic activity decrease. The estimated environmental benefits from reductions in air emissions are considerable and larger than the gain from reduced waste amounts. This confirms the importance of studying waste policy instruments in a broadest possible framework, as the waste problems are entangled with other environmental problems and waste policies have important implications on markets outside the waste field.

Ideally the tax should be set at a level where the marginal costs of a tax equal the marginal treatment costs. The optimal taxes can only contribute to reductions, not elimination, of the waste amounts. For the remaining wastes spread on a mixture of recycling, incineration and landfill, the marginal costs should be equal for each alternative.

The tables 1-4 display the cost efficient policy hierarchy for residential and commercial paper and plastic waste. These conclusions concern the *marginal costs* (as opposed to average costs) including both short term and long term marginal costs from transportation of waste, and construction and use of new disposal facilities. The cost notion concerns net costs, as revenues from i.e. sale of recycled products, energy from incineration are included. Before looking into the numbers in the tables, keep in mind that the sources and assumptions behind the tables are explained in the chapters 3 to 6.

Table 1. Ranking of the waste policy options for *residential paper* waste. Marginal costs based on chosen estimates and cost interval in parenthesis, NKr per tonne

	1 Source reduction	2 Incineration	3 New landfill	3 Recycling	4 Old landfill
Cost components:					
Households' collection costs				1 003 (290 - 1 716)	
Conventional collection costs		531	531	904	531
Collection air emissions costs		73	73	408	73
Processing conventional costs		235	235	95	119
Area costs			100 (-5-100)		100 (-5-100)
Processing emissions costs		479 (247-482)	1319 (247-1 941)		2 433 (294-3 676)
Total		1319	2258	2410	3255
Cost interval		(1 200-1 300)	(1 100-2 900)	(1 700-3 100)	(1 000-4 500)

Table 2. Ranking of the waste policy options for *commercial paper* waste. Marginal costs based on chosen estimates and cost interval in parenthesis, NKr per tonne

	1 Source reduction	2 Recycling	3 Incineration	4 New landfill	5 Old landfill
Cost components:					
Conventional collection costs		573	667	667	667
Collection air emissions costs		408	73	73	73
Processing conventional costs		-150	235	235	119
Area costs				100 (-5-100)	100 (-5-100)
Processing emissions costs			479 (247-482)	1 319 (247-1 941)	2 433 (294-3 676)
Total		831	1 455	2 394	3 392
Cost interval			(1 300-1 500)	(1 200-3 000)	(1 100-4 600)

2.2. Residential paper waste

After *source reduction* on the top of our hierarchy, *incineration* is the second most efficient alternative for residential paper waste (paper waste from households), see table 1. *Recycling* and *new landfills* rank about equal. The cost of landfills are mainly due to large methane emissions (labeled as processing emission costs in table 1). In new landfills, 50 per cent of the methane emissions are collected, which reduces the costs by 30 per cent, and the seepage is reduced by improved liners.

The largest cost component for recycling is the mean households' time costs. Compared to the net hourly wages in Norway, the chosen time cost estimate is conservative (NKr 53 per hour). Using the lowest cost estimate (NKr 35 per hour), does not change the ranking. Also the conventional collection costs and air emissions from transport are higher than for incineration and landfill.

Disposal of residential paper waste on *old landfills*, without gas collection systems, is the most costly alternative.

2.3. Commercial paper waste

For commercial paper waste (paper waste from businesses) we have not included extra sorting time costs, see table 2. Also, collection costs are lower for recycled commercial waste than for residential waste and the sale of processed commercial paper waste involves net profit due to high prices on recycled high quality paper. Thus, the costs of recycling is relatively low, and after *source reduction* the preferable alternative is *recycling*. *Incineration* ranks after recycling. *Landfill* is more costly due to the methane emissions, which are largest for old landfill without gas collection.

Table 3. Ranking of the waste policy options for residential plastic waste. Marginal costs based on chosen estimates and cost interval in parenthesis, NKr per tonne

	1	2			3
	Source reduction	New landfill	Old landfill	Incineration	Recycling
Cost components:					
Households' collection costs					1 003 (290-1 716)
Conventional collection costs		1 254	1 254	1 254	3 763
Collection air emissions costs		171	171	171	1 700
Processing conventional costs		479	242	-166	235
Area costs		100 (-5-100)	100 (-5-100)		
Processing emissions costs		583 (225-888)	895 (242-1 338)	1400 (334-3 224)	
Total		2 587	2 662	2 660	6 702
Cost interval		(2 100-2 900)	(1 900-3 100)	(1 700-4 500)	(6 000-7 400)

Table 4. Ranking of the waste policy options for commercial plastic waste. Marginal costs based on chosen estimates and cost interval in parenthesis, NKr per tonne

	1	2			3
	Source reduction	New landfill	Old landfill	Incineration	Recycling
Cost components:					
Conventional collection costs		1 461	1 461	1 461	2 965
Collection air emissions costs		171	171	171	1 700
Processing conventional costs		479	242	-166	337
Area costs		100 (-5-100)	100 (-5-100)		
Processing emissions costs		583 (225-888)	895 (242-1 338)	1 400 (334-3 224)	
Total		2 794	2 869	2 867	5 003
Cost interval		(2 300-3 100)	(2 100-3 300)	(1 900-4 700)	

2.4. Plastic waste

For plastic waste, the conventional incineration costs are negative due to high energy value, see tables 3 and 4. The environmental processing costs are higher than for landfill, while the collection costs are assumed the same, and *landfill* and *incineration* are about equally costly. The emissions costs from incineration are the highest cost components. The reason why new and old landfills are ranked about equal, is that while conventional landfill costs are higher in new landfills, these outweigh the effect of reduced methane emissions.

Recycling is the most costly alternative for plastic, mainly due to high conventional collection costs, but also because of high air emissions costs from transport.

2.5. Factors not accounted for

2.5.1. Recycled versus virgin materials

We have not calculated the difference in costs from using virgin versus recycled material inputs. On one hand the use of recycled paper and plastic saves trees, oil reserves and extraction costs, while on the other there are costs from transforming the recyclables from waste to material inputs. REFORSK (1993) studies the environmental effects of different treatments methods based on Swedish data, and evaluates particularly the aspect of whether the incinerated material substitutes other energy sources. The environmental outcome is ambiguous, as it depends on what heat source competes with waste incineration. If incineration competes with fossil fuels, incineration can be a better alternative than recycling. In their life cycle studies Schall (1993) and Breslow (1993) conclude that the social costs of virgin materials are higher than of recycled materials. However, these results are disputed by leading experts in the solid waste field[1].

[1] See e.g. the comments by Alter and Scarlett in MSW Management (1993) and Goddard (1995).

It is frequently argued that the virgin materials prices are too low, since important external costs are not included, and that these price failures are a major reason behind the costs associated with waste (see e.g. Miedema 1983, Repetto 1994, or Bruvoll 1998). If the virgin material prices are too low, the prices should be corrected for the externality costs rather than dealing with the emission problems with recycling. Our source reduction alternative is an analysis of the consequences of correcting virgin material prices.

Also, the quality of the products is also usually lower, such that the weight on the product based on recycled materials is higher (Ministry of Environment 1993).

2.5.2. Environmental recycling processing costs

As also can bee seen from the tables, the environmental recycling processing costs are not accounted for. In the process of de-inking paper new wastes are generated. A de-inking mill processing a tonne of paper disposes 40 kilos of solid waste and between 2 and 5 kilos of waste sludge in dry weight (DeLong 1994b). De-inking also uses about 60 000 liters of water per tonne of paper processed, which become contaminated and require significant treatment before discharge.

Another important additional cost of recycling is that a share of the recycled materials can not be used in the product, about 15 per cent of the input factor collected cardboard waste end up as waste that must be incinerated or landfilled (Ministry of Environment 1993). These double treatment costs are not accounted for, due to lack of detailed information on paper and plastics waste.

2.5.3. Lack of market

A problem frequently debated is the lack of market for recycled products. Due to high prices on recycled relative to virgin materials, large amounts of waste accumulate. In many cases collected paper has finally been burned or landfilled, or transported abroad.

Mandatory regulations designed to force up the demand for recyclables will artificially raise the prices on recylable materials. The US federal government, the world's largest buyer of paper, requires that the paper it purchases has 20 per cent recycled content, which guarantees a huge market for recycled paper without securing a least cost waste treatment. Lately the American recycling market has extensive problems in the recycling market due to high recycling expenses relative to virgin material prices (The Economist 1997). Scarlett (1993a) points at major legislative endeavors which have been proposed to stimulate or force the use of recyclables, with the result that the supplies of recyclables have outstripped the growth in demand.

Price increases may also deter entrepreneurs outside the mandated end uses from exploring ways of using these materials in other products.

2.5.4. Other factors

Tellus' data on transport emissions does not include emissions of climate gases. Since transport emissions are highest for recycling, implementation of climate gases would increase the relative recycling costs.

Mandated recycling implies costs for private businesses. One study estimated that New York businesses would spend up to $1 billion per year to comply with proposed recycling laws (DeLong 1994b). The political recycling goals are usually implemented as recycling mandates, and the administrative costs, the control costs and the costs of motivating and educating the households can be of significant size.

The products based on recycled materials often create new markets, which not necessarily substitute the products based on virgin materials. Fletcher and Mackay (1990) show that when recycled plastic replace virgin material, plastic waste is reduced by the same amount, while under new markets there is no effect on the amount of generated plastic waste. In these cases, the benefits of recycled vs. virgin materials are highly reduced.

Finally, the loss in property values nearby landfills are not accounted for. Several studies reveal that the housing values rise with the distance from a landfill, one study shows that the values rise by an average of 6.2 per cent a mile (1 600 meters) within a two-mile radius of the landfill (Beede and Blom 1995).

Despite the lack of some data, the largest components should be included in the cost estimates. Based on the significant differences in the costs, we conclude that our study provides important guidelines on how to implement the least costly waste policy for paper and plastic waste, and that a general acceptance of recycling as the preferable alternative is misleading. We now turn to describing the methods and data used in estimating the costs of the different policy alternatives.

3. Source reduction

While recycling, incineration and landfill are methods of treating already generated waste, another focus is on reducing waste generation. As argued by Goddard (1995), there are very good theoretical reasons to believe that significant levels of source reduction can be attained at a lower cost than that of all the other solid waste management alternatives. Waste management services are usually paid over constant rates, independent of delivered volumes. Thus the prices per unit facing the waste generators are by large very low or zero. The marginal cost of source reduction (marginal abatement cost) is equally low. Therefore there exists a yet unknown range over which a charge for waste management services will create a cost to the consumer and the community necessarily less than the cost of increased recycling, incineration or landfill.

A source reducing tax will influence the economy in many respects, both positively, e.g. via less emission costs from all sectors facing increased production costs, and negatively, as less consumption due to a slowdown in economic growth. To trace the total net effects of such a tax, a macroeconomic model is required. Actually, as we mentioned under the main results, other environmental benefits due to the macroeconomic functioning appear to be larger than the direct benefits of reduced waste.

We have levied a tax of 15 per cent on the material inputs used to produce paper and plastic products; paper and plastics raw materials within the general equilibrium model MSG[2]. The aim is to reduce the production of waste generating products and the costs associated with treatment of these wastes. According to available cost figures this tax is far below both the estimated treatment and environmental costs of the use of paper/plastic virgin materials. In this paper we will summarize the main features of the model and the main results. A full documentation of the tax reform can be found in Bruvoll (1998).

3.1. The model

MSG models the Norwegian economy (see Holmøy, Nordén and Strøm 1994 and Alfsen, Bye and Holmøy 1996). Total production growth is largely determined by growth in the supply of primary resources as real capital, labor, virgin materials and natural resources and by technological change. The base year on our study is 1988, and the model is simulated over the period 1988-2030. The model specifies 33 production sectors and 48 goods (of which 10 are non-competing imported goods and 4 are public goods), reflecting a compromise between the ambition of applying detailed sector information, and the need for a manageable model. MSG describes a general equilibrium, where demand equals supply in all markets, and domestic producer prices equal sectoral unit costs in most sectors.

In most sectors the firms are assumed to behave competitively on both output and input markets. The demand for inputs follows a recursive budgeting procedure involving several stages. At the top level there are five input factors: labor, capital, energy, transport services and materials. These factors are optimally combined to minimize costs, according to constant returns to scale technology. The input factors energy and transport are then further divided. The model assumes exogenous technological and organizational progress.

Prices of imports including energy and the interest component in the price of capital are determined in the world market, i.e. treated as exogenous in the model. The capital goods and material input prices are ultimately, through the input-output structure, functions of the wage rate, productivity, import prices, the interest rate, indirect tax rates, exogenous prices and the fixed exchange rate. Technological progress reduces the prices of produced factors, and thus the prices of material inputs and capital goods decrease relative to the labor price, which causes a substitution from labor input to more use of material inputs over time.

[2] The model applied specifies material inputs as one commodity with no possibilities of substitution between the various material inputs, and the taxed virgin materials are part of the commodity aggregate. We have calculated a sector-specific tax which corresponds to the share of paper/plastic raw materials in relation to total material inputs within each sector.

MSG models 8 polluting air emissions by fixed components to the emission sources transport, intermediate deliveries and fuel oil for heating.

In the baseline scenario, net domestic product[3] grows by a good 50 per cent and private consumption by more than 100 per cent in the period 1997 to 2030. Total material inputs rise by nearly 50 per cent in the same period. The baseline waste growth projections run to 2010 only, and indicate a growth of 74 per cent in generated plastic, paper and cardboard waste from 1993 (Bruvoll and Ibenholt 1997).

Higher material input prices result in substitution from material inputs to labor, capital and energy[4]. At the same time, higher costs reduce production, which amplifies the reduction in the use of material inputs and also contributes to a general reduction in the use of other factor inputs. Higher product prices also have secondary effects on the material input prices, as material inputs are produced commodities. These effects are most significant in the sectors with the highest taxes. This is ascribable to improved relative competitiveness and shifts in production from sectors with the greatest cost increase.

Material inputs are important input factors in the production of capital. The tax on material inputs in the sector for intermediate inputs and capital goods spreads in the form of higher capital prices and a reduced use of capital and a lower total activity level. Material inputs are relatively large in relation to the gross value of production, thus changes in the gross value of production correlate closely to the material inputs changes.

3.2. Results of the tax reform

A material tax encourages reduced use of virgin materials and thereby reduced generation of waste. The tax also increases the product prices, reduces the demand for and production of products based on these virgin materials and further stimulates source reduction. Plastic, paper and cardboard wastes amount to about 640 000 tonnes annually in Norway (Bruvoll and Wiig, 1996), and increase to 1500 000 tonnes in 2030 according to the baseline scenario.

Compared with the projections, the tax results in a reduction in total generated quantities of about 168 000 tonnes in 2030. The treatment costs vary highly between treatment method and waste, from NKr 800 at recycling commercial paper waste to NKr 6 700 at recycling residential plastic waste (recall tables 1 to 4). With unchanged damages per tonne of packaging waste and an interval of collection and treatment costs of NKr 800-6 700, this implies reduced total costs of between NKr 140-1 130 million in 2030.

[3] Gross domestic product less capital consumption.
[4] These may be complementary to material inputs in some sectors.

Table 5. Changes in key variables in 2030 as a result of 15 per cent tax on paper/plastic raw materials, per tonne reductions in paper/plastic raw materials.

	Best guess estimates	Interval, lowest and highest estimates
Reduced packaging waste	54 kilos	
Reduced waste treatment costs		NKr 45-364
Reduced air emission costs	NKr 361	NKr 219-745
Reduced consumption	NKr 204	
Reduced net domestic product	NKr 1 023	
Reduced material input	NKr 4 763	

Increased material input prices rise the overall cost level for the producers. These higher costs reduce production. Net domestic product is reduced by totally NKr 3.2 billion. Due to less production, consumption is also reduced. The consumption loss is a more direct measure of the welfare loss from increased overall costs, and amounts to NKr 600 million.

On the other hand reduced production leads to less air emissions. The environmental gains from reduced air emissions are even larger than the gain from reduced waste amounts. The environmental gain associated with changes in emissions to air is between NKr 680 million and NKr 2.3 billion, according to highest and lowest estimates of environmental costs. According to our chosen cost estimates (see table A1), the gain amounts to NKr 1 100 million. CO_2 emissions decline the most, by 3.2 per cent, and amounts together with particulate matter to the largest environmental benefit. Totally, the environmental changes which are taken into account above provide a gain of between NKr 820 million and NKr 3.4 billion, depending on the valuation study applied.

The main benefit and cost components from this analysis are summarized in table 5. To compare with the costs of recycling, incineration and landfill, we have normalized the numbers in terms of per tonne use of paper/plastic raw materials. When measuring the outcome of waste policies, the current use of virgin materials can be argued to be a more relevant measure than the change in current waste amounts. By the basic rule of mass balance, all materials entering the economic system from nature as virgin materials eventually are disposed in the nature, either to air, land or water. This implies that the current extraction of virgin materials equals the future amounts of waste and emissions. Since the study of source reduction reveals the effect on material inputs, we present the results from this analysis per tonne paper/plastic raw materials.

As we see from table 5, the benefits of *reduced waste treatment costs* on between NKr 50-360 per tonne paper/plastic raw material alone are in line with the costs of the tax reform measured as *reduced consumption* on NKr 200 per tonne. If we alternatively look at the costs in terms of *reduced net domestic product*, which is a broader indicator of the reduction in the overall activity level, the costs are significantly higher than in terms of consumption.

However, adding the benefits of the *reduced air emission costs* to the reduced waste treatment costs, the environmental gains amount to NKr 300-1 100 per tonne paper/plastic raw material, which is in line with the reduction in net domestic product on NKr 1 000 per tonne.

Additional to these environmental benefits are some considerable benefit factors which are more difficult to quantify, but which strengthens our conclusion of a net benefit outcome. First, we have not evaluated the *total reduction* in paper/plastic raw materials, but only the reduction in packaging waste. For many products based on the same material inputs, as packaging products, the time lag from when materials enter the production process to the products end up as waste is probably within one year, while e.g. for building products it takes considerably longer time. The reduction in the total use of paper/plastic raw materials in 2030 is estimated to be 18 times greater than the reduction in packaging waste.

We have no data indicating the average life time of these materials, thus it is not possible to trace a time profile and discount the effects. To illustrate the possible extent of this environmental benefit, if the average life time of paper/plastic products are 5 years and given a social discount rate of 7 per cent, the future gain due to reduced treatment costs amounts to between NKr 2 and 15 billion (between NKr 600 and 4800 per tonne reduction in paper and plastic raw materials). In the more extreme case of zero discounting[5], the gain increases by 40 per cent. Despite its uncertainty, this illustration clearly shows that the environmental benefits from less use of paper/plastic material input contribute to a positive net outcome of the tax reform.

The second and probably even more important environmental consequence not accounted for is related to the rest of material inputs, other than paper/plastic raw materials. It is reasonable to assume that a general reduction in the use of material inputs results in reduced environmental damages. *Material inputs* decline by 1.5 per cent, equivalent to totally NKr 15 billion (NKr 4 800 per tonne reduction in paper and plastic raw materials). The reduction in the value of material inputs additional to paper/plastic raw materials in sectors with a tax is 14 times greater than the reduction in paper/plastic raw materials[6]. Due to lack of relevant estimates on damages we can not comment on the magnitude of these environmental gains. Also, improved environmental quality will increase productivity, and in turn, as shown in Bruvoll, Glomsrød and Vennemo (1998), curbs the decline in production and consumption. The model used does not implement such feedback mechanisms from the environment to the economy.

Another environmental factor is the waste-reducing effects of packaging waste. As stated in Alter (1991), there is no generally accepted ways to measure waste reduction. One reason is that steps to decrease the amount of one waste may increase the amount of another. Correlation analyses show that the decreased amounts of plastic packaging correspond to an increase in food waste residues. US data show that a tonne less of plastic packaging was associated with a 1.65 tonne increase in food waste, and 1.41 tonne in the case of paper and cardboard (Alter 1991). Thus less packaging waste can correspond to increased amounts of food wastes.

3.3. Other studies

Several other studies confirm the net gain of material taxes. Statistics Norway has earlier carried out an analysis of a general tax on all types of material use, in a model where improved environmental quality has positive feedback on the productive economy (Bruvoll and Ibenholt 1998). This analysis shows a clear, positive environmental effect in the form of reduced air emissions and waste quantities, although the total welfare effect is uncertain due to reductions in production and material consumption.

Pearce and Turner (1993) conclude in their analysis of the comparative merits and limitations of political approaches to waste management that either virgin materials taxes or product charges could be imposed to correct for market failures. Also, these market based instruments offer more cost-effective solutions to the problems of packaging waste and litter than regulatory legislation.

We now turn to describing the different treatment options and the underlying data in the tables 1 to 4.

[5] Despite the standard approach, discounting is subject to an extensive ethical debate. Discounting implicitly accounts for our descendants' possibility of non-existence, or we evaluate their well-being lower than our own. Vennemo (1996) shows that under weak assumptions, environmental goods should be discounted at a lower rate compared to market goods, or maybe not at all. Also Cline (1992) and Broome (1992) have argued for the use of a zero discount rate in the context of global warming. Rawls (1972) represents an even more critical view, as he argues that a negative discount rate is as morally sound as today's discounting of the future.

[6] Due to the model specification, the tax is levied on all material inputs. The reduction in paper/plastic raw materials is probably underestimated and thus the reduction in other material inputs overestimated compared to if there were substitution between paper/plastic raw materials and other material inputs.

4. Recycling

The current level of recycling is not a result of optimal economic behavior, but a result of politically determined recycling targets. Some level of recycling has always been profitable, while mandated recycling creates artificial markets, and opens for misallocation of resources. In our data, the marginal costs of recycling exceed the marginal costs of all other treatments. Despite the relatively high recycling costs, the recycling targets on packaging waste in Europe are generally above 60 per cent (Brisson 1993). The Norwegian policy is in line with the EU's directive on packaging waste, which requires that between 50 and 65 per cent of the total packaging waste shall be recycled. Specifically, the target for brown paper is 65 percent, and for plastics 30 percent.

4.1. Households' collection costs

One major reason for the popularity of recycling, is that recycling makes people feel that they contribute to solving environmental problems in their daily lives. As this study shows, this understanding can be misleading. In any case, the private time use has an alternative value. Based on time costs between NKr 35 to 70 per hour, DeLong (1994b) estimates the US households' time costs of sorting waste to between NKr 310 to 1 850 per tonne, even when households spend less than 15 minutes a week on the task. This is also a conservative estimate compared with hourly net wages in Norway. We have used the average from DeLong as chosen estimate.

4.2. Conventional collection costs

The estimates for conventional collection costs are based on Tellus' (1991) American estimates over residential and commercial collection of recyclable materials, see table A2. Vehicles that collect materials fill up by volume. Also, compared with unsorted and compressed waste recycled paper requires 2-4 times the space, and 4-11 times the space for plastics[7].

The Ministry of Environment (1995) estimates the conventional collection costs from retail businesses in Norway. About half the plastics can be collected at a cost of NKr 1130 per tonne, while the marginal costs increase rapidly for additional amounts, up to NKr 5 770 per tonne. Tellus' (1991) marginal cost estimate for commercial plastic is NKr 3 000 per tonne and fits nicely within this interval.

The collection costs decrease with increasing size of the programs (Glenn 1992). Also, the amounts and thus the costs per tonne are highly dependent on education and motivation for recycling.

4.3. Collection air emissions costs

The collection emissions are estimated in Tellus (1991), see table A3. These numbers are also based on American assumptions, as e.g. truck collection distance. Compared with other recycled materials, plastics are among the materials with the highest costs per tonne, because of the low material density. The emission cost estimates in table A4 are based on the cost estimates in table A1. Emissions of particulate matter contribute to about 50 per cent of the total costs, while benzene emissions account for 36 per cent.

4.4. Processing conventional costs

Processing may involve separation of the material from other materials or mixed waste, contaminant removal and volume reduction. The variety of processing methods complicate generalizations of cost estimates. The estimates for conventional processing costs are found in Tellus (1991), and are based on models that assume a mix of several processing methods. The methods are different for residential and commercial wastes. For further details on the estimates, see table A5.

4.5. Environmental extraction and processing costs

In lack of current data, the environmental extraction and processing costs from recycling are not accounted for in this analysis. Among these components are environmentally damaging emissions from the processing of recycled materials and the saved costs of extracting virgin materials, see chapter 2.5.

[7] Tellus (1991), tables 6.3 and 6.4.

4.6. Other studies

The recycling cost studies offer a great spread in estimates, as they include different variables. Generally, they do not include the environmental consequences. We will briefly refer to some relevant studies.

In a study from Pennsylvania, estimates of the economics of recycling varied from a profit of $43 to a loss of $723 per tonne (DeLong 1994b). The result of economic losses is highly subsidized recycled products, or landfill of materials which are segregated by consumers. Brisson (1993) calculates the revised per tonne cost in the German green dot program to about $266, while the average collection and landfill costs range from $59 to $89 per tonne. Scarlett (1993a) reports that recycling programs are often more expensive than other waste treatment options, and in Massachusetts recycling programs have increased total waste management costs. Based on 7 recycling programs the net costs of recycling range from 5 to 7 times the national average landfill costs (Goddard 1995 and Scarlett 1993b).

Some cost studies find that recycling can be economically profitable. A study on costs and benefits of recycling in Taiwan shows a positive net income of recycled products. Yu et al. (1996) conclude that the recycling programs derive almost sufficient income from the sale of recyclable materials to cover all expenses. When subtracting the saved landfill costs of $58 per tonne, recycling gives a net benefit, environmental costs excluded.

5. Incineration

Compared to recycling, incineration represents a more traditional solution to waste treatment. Incineration is only partly a waste disposal method. Some of the materials are disposed of as air emissions, while for the rest of the waste, incineration represents rather a waste processing technology reducing the volume. Damaging air emissions from waste incineration include several toxic and acid gases and to some extent climate gases. Incineration greatly increases the mobility of toxic materials in a form that is more easily absorbed by living organisms than the same materials in unburned waste. However, new technology offers solutions to prevent most of the environmentally damaging emissions. Incinerated waste can also be used for energy production, which is reflected in lower conventional incineration costs.

5.1. Conventional collection costs

The collection costs for waste to incineration (and landfill) are significantly lower than for recycling, especially for plastics waste, since the materials can be more compacted. The chosen estimates are based on Tellus (1991) garbage collection costs for different materials, see table A6. The collection costs for commercial waste are higher than the collection costs for residential waste.

5.2. Collection air emissions costs

As for recycling, the emissions per tonne collected waste are estimated in Tellus (1991), and the principles for evaluating the damages are also the same as described under recycling. The environmental costs of garbage collection are mainly due to fuel emissions of collection and transport trucks. See table A7 and A8 for further details.

5.3. Processing conventional costs

The cost estimates are found in Tellus (1991), based on the costs of one planned and three old facilities in California. See table A9 for further details. The net marginal costs include capital and operating costs, residue disposal costs and revenue from the sale of electricity[8].

5.4. Processing emissions costs

Cadmium is evaluated to be the most environmental damaging component of the incineration of paper, followed by particulate matter, dioxins and NO_x, while CO_2-emissions are clearly most costly when burning plastic, see table A10 for more details.

Incinerators reduce the mass from 10 to 25 per cent of the original waste volume (Chilton 1993), and must after burning be treated as hazardous waste. Damaging air emissions from waste incineration include several toxic and acid gases and climate gases from plastic waste. Incineration greatly increases the mobility of toxic materials in a form that is more easily absorbed by living organisms than the same materials in unburned waste. However, new technology offers solutions to collecting most of the toxic substances, modern incinerators remove most of the air pollutants through high temperature and filtering. New waste to energy facilities in US are estimated to pose a 1 in one million cancer risk (Chilton 1993).

The incineration costs per tonne waste are estimated in ECON (1995), which is based on a extensive comparison of different studies on national and international data, among them Tellus (1991, 1992) and Det Norske Veritas (1995). We have used other estimates for particulate matter, based on a more recent study. The low and high estimates in table A10 are computed on the basis on the relative differences in table A1.

[8] For mixed wastes, the capital and operating costs amount to about NKr 650 per tonne, residue disposal costs to NKr 25 per tonne and and revenues to NKr 40 per tonne. In Norway, plastics are burned mixed with other materials, and the fuel value is between NKr 400 and 750 per tonne (Bruvoll and Wiig 1996).

6. Landfill

Landfill represents the final end of a material's life cycle. Landfills are traditionally known to be sources of ground water contamination and other leakage, smell problems from anaerobic degradation and emissions of climate and other damaging gases.

The latest years stricter regulations have reduced the environmental damages also from new landfills. The external costs are reduced with systems which prevent, collect and process leaking, collect and vent or burn methane gas, and procedures secure safe management or exclusion of hazardous waste disposal. On the other hand, the long term consequences are uncertain as all structures, as liners, leakage collection systems and cover systems have finite lifetimes, whereas the wastes and their toxic emissions will continue to exist for generations. The trend has been towards larger fewer landfills, which has given a sharp fall in the average treatment costs.

6.1. Collection costs

As for incineration, the estimates on conventional garbage collection costs are based on Tellus (1991). The air emissions from collection of waste for incineration and landfill are assumed equal. For further details, see table A6 and A8.

6.2. Processing conventional costs

The conventional landfill costs are estimated in Tellus (1991), including capital, operating, closure and post-closure costs, see table A11. New landfills are assumed to be lined and to have a gas collection system, while the existing are unlined and without gas collection.

The average treatment costs fall sharply with the size of the landfills. Evidence from US suggests that the average cost of operating sanitary landfills declines by about 70 per cent as their capacity increases from 227 to 2 700 tonnes a day (DeLong 1994a). The trend is also towards larger and fewer landfills, in Norway the number of landfills were reduced from about 400 at the end of the 70's to 208 in 1995 (Statistics Norway 1997). On the other hand, larger landfills entail larger environmental and economic transport costs.

6.3. Area costs

The landfill area costs in the Tellus study only amount to 2.6 per cent of the total costs, equaling NKr 5 per tonne. The average landfill height is assumed to be between 24 and 40 meters, which is considerably higher than the Norwegian average of about 6 meters[9]. We have estimated the landfill area costs based on Norwegian data, which are higher, partly due to the landfill height. It is assumed that the same amount of area actually landfilled is bound up in roads, buildings and safety area. The estimated area costs amount to NKr 105 per tonne waste, an additional NKr 100 per tonne compared to Tellus' numbers, see 8.4 in Appendix. The low estimate is on NKr 0 per tonne.

6.4. Processing emissions costs

Landfills are traditionally known to be sources of ground water contamination and other environmentally damaging leakage, smell problems from anaerobic degradation and air emissions. Methane emissions from landfills dominate the environmental costs due to landfills and incineration of waste in Norway (Bruvoll and Wiig 1996), 12 per cent of the total Norwegian climate gas emissions stem from anaerobic decomposition of organic waste at landfills (Statistics Norway 1997). Globally, about 6 per cent of total methane emissions origin from landfills (Beede and Blom 1995).

The landfill emission costs per tonne waste are estimated in ECON (1995), based on different studies on national and international data, see table A12. The low and high estimates are computed on the basis of the relative differences in table A1. The dominating cost factor in the chosen estimate is methane emissions, which amount to 85-90 per cent of the costs of landfilled paper, and 55-70 per cent of the costs of landfilled plastics. Due to the high relative damage of methane emissions, the emission costs of landfill are almost halved when 50 per cent of the climate gases are collected.

[9] The world largest landfill on Staten Island is planned to reach a height of more than 130 meters.

The cost estimates of climate gases are very uncertain, both since the emissions are spread over time, and since the long term effect depend upon the discount rate. Thus there is a great spread in damage estimates. The low cost estimate in table A12 is based on Statens Forurensningstilsyn (1995a), while the high cost estimate reflects the tax necessary to stabilize Norwegian emissions on 1989-level. The chosen estimate accords to the current carbon taxes in Norway.

2-Butanon is the second dominating factor among the leakages. The other toxic leakages contribute to relatively small damages. A computer model of 6 000 landfills in US estimates virtually no risk in 60 per cent of the facilities, only 6 per cent pose a cancer risk lower than 1 in 10 000 (Chilton 1993). Estimated aggregate risk from existing landfills in US is one cancer death every 13 years. On the other hand, specific for landfill is that the long term consequences are uncertain as all structures, as liners, leakage collection systems and cover systems, have finite lifetimes, whereas the wastes and their toxic emissions will continue to exist for generations.

7. Conclusions

This study supports that on the margin source reduction carried out as a tax on material inputs is preferable to the waste treatment alternatives recycling, incineration and landfill. Ideally the tax should be set at a level where marginal costs of a tax equal the marginal treatment costs. For the remaining wastes spread on a mixture of recycling, incineration and landfill, the marginal costs should be equal for each alternative.

Despite the standard understanding that recycling is the environmentally best alternative, our data shows that incineration and landfill are more costly only for commercial paper waste. As the underlying level of recycling is set too high, the marginal costs of recycling are higher than of the alternative treatments. In fact, for plastic waste, recycling is the most costly alternative for both residential and commercial waste. The main recycling costs are the collection costs, which vary between the localities. However, given equal collection costs for recycling, incineration and landfill, recycling of residential waste is not less costly than the other alternatives. These conclusions are supported by other cost studies and studies on the use of price incentives.

Due to the nature of environmental evaluation, the cost estimates are only indicative on the actual cost levels. We have also considered intervals of cost estimates, and our main conclusions are robust to alternative estimates. The analysis includes the most relevant factors, but we have also pointed out some factors not accounted for which might influence the estimates. The data also relies on the underlying technology and prices at the current time. This study shows that further analyses are needed to look into local conditions and other materials before determining ambitious recycling targets. There is nothing such as a general hierarchy for all wastes.

Recycling can not alone meet the growing waste amounts. The latest three years the total waste amounts have grown 3 times more than the amounts for recycling. The last 15 years the amounts have grown by 50 percent, and projections show the same growth in the future, due to high growth in consumption and material input (Bruvoll and Ibenholt 1995a and 1995b).

The political implication for the future policy planning would be to put more weight on the use of economic incentives, in line with the recommendations from the Green Tax Commission (Ministry of Finance 1996). Today the local authorities can differentiate the prices waste collection services according to the amount delivered. However, only a few communities use variable rates, and the households' possibilities to reduce the waste service costs by generating less waste are limited. A long range of studies evaluating international experiences shows that per unit pricing of delivered waste has positive effects on waste generation as well as the economics of recycling[10]. An end treatment tax can meet the negative effects from waste treatment, as an alternative to recycling, incineration and landfill.

[10] See e.g. Ackerman et al. (1992), Chilton (1993), Meissner and Leknes (1994), Project 88-II (1991), Repetto et al. (1992), Rogalandsforskning (1996), Scarlett (1993a) and Skumatz (1993 and 1996).

References

Ackerman, F., J. Stutz, M. Breslow and D. Samuels (1992): Feasibility of volume-based collection fees for private waste haulers, Tellus Institute, S2-206.

Alfsen, K. H., T. Bye and E. Holmøy (1996*): MSG-EE: An applied general equilibrium model for energy and environmental analyses*, Social and Economic Studies 96, Statistics Norway.

Alter, H. (1991): The future course of solid waste management in the US, *Waste Management and Research* **9**, 3-20.

Beede, D. N. and D. E. Blom (1995): The economics of municipal solid waste, *The World Bank Observer* **10**, 2, 113-50.

Bernstein, J.-D. (1993): Alternative approaches to pollution control and waste management: Regulatory and economic instruments, Urban management and the environment series, no. 3. Washington D. C.: World Bank for the UNDP/UNCHS/World Bank Urban Management Programme, 1993.

Brendemoen, A., S. Glomsrød and M. Aaserud (1992): *Miljøkostnader i makroperspektiv* (Environmental costs in a macro-perspective), Reports 92/17, Statistics Norway.

Breslow, M. (1993): Regulating solid waste externalities through tax/free systems, Dissertation, University of Massachusetts.

Brisson, I. (1993): Packaging waste and the environment: Economics and policy, *Resources, Conservation and Recycling* **8**, 183-292.

Broome, J. (1992): *Counting the cost of global warming*, London: White Horse Press.

Bruvoll, A. (1998): Taxing virgin materials: an approach to waste problems, forthcoming in *Resources, Conservation and Recycling.*

Bruvoll, A., S. Glomsrød and H. Vennemo (1998): Environmental drag: evidence from Norway, forthcoming in *Ecological Economics*.

Bruvoll, A. and K. Ibenholt (1995a): Framskrivning av avfallsmengder i Norge (Projections of wastes in Norway), *Økonomiske analyser* 8/95, Statistics Norway.

Bruvoll, A. and K. Ibenholt (1995b): Projections of waste quantities in Norway, *Economic Survey* 4/95, Statistics Norway.

Bruvoll, A and K. Ibenholt (1997): Future waste generation. Forecasts based on a macroeconomic model, Resources, *Conservation and Recycling* **19**, 137-49.

Bruvoll, A. and K. Ibenholt (1998): Green throughput taxation. Environmental and economic consequences, forthcoming in *Resource and Environmental Economics*.

Bruvoll, A. and H. Wiig (1996): Konsekvenser av ulike håndteringsmåter for avfall (Consequences of different waste treatment methods), Notater 96/31, Statistics Norway.

Bystrøm, S. and L. Lønnstedt (1997): Paper recycling: environmental and economic impact, *Resources, Conservation and Recycling* **21**, 109-27.

Chilton, K. (1993): Solid waste policy should be directed by fundamental principles, not ill-founded feelings. Resources, *Conservation and Recycling* **8**, 1-20.

Cline, W. R. (1992): *The economics of global warming*, Institute for international economics ,Washington D.C.

DeLong, J. V. (1994a): Of mountains and molehills: The municipal solid waste “crises”, *Brookings Review* (spring), 32-39.

DeLong, J. V. (1994b): Wasting away. Mismanaging municipal solid waste, Environmental studies program, Competitive Enterprise Institute, Washington D.C.

Det Norske Veritas (1995*): Miljømessige virkninger ved utsortering av avfall* (Environmental consequences of sorting waste), Det Norske Veritas Industri Norge AS and Statens Forurensningstilsyn, Report 95-3119.

ECON (1995): *Miljøkostnader knyttet til ulike typer avfall* (Environmental costs of different wastes), ECON-rapp. 338/95.

Fletcher, B. L. and M. E. Mackay (1996): A model of plastics recycling: does recycling reduce the amount of waste? *Resources, Conservation and Recycling* **17**, 141-51.

Goddard, H. C. (1995): The benefits and costs of alternative solid waste management policies, *Resources, Conservation and Recycling* **13**, 183-213.

Glenn, J. (1992): Efficiencies and Economics of Curbside Recycling, *Biocycle* **33**, 7, 30-34.

Heijungs, R. (red.) (1992): *Environmental life cycle assessment of products. Guide and backgruound*, Centre for Environmental Science, Leiden Universitet, Leiden, Nederland.

Holmøy, E., G. Nordén and B. Strøm (1994): *MSG-5, A complete description of the system of equations*, Reports 94/19, Statistics Norway.

Holtskog, S and K. Rypdal (1997): *Energibruk og utslipp til luft fra transport i Norge* (Energy use and transport air emissions in Norway), Reports 97/7, Statistics Norway.

Meissner, R., and E. Leknes (1994): Evaluering av systemer for differensiering av gebyr for husholdningsavfall (Evaluation of systems for differentiated fees for household waste), Rogalandsforskning 292/94.

Miedema, A. K. (1983): Fundamental economic comparisons of solid waste options, *Resources and Energy* **5**, 21-43.

Ministry of Environment (1993): Increased collection and recycling of brown paper in Norway (Increased collection and recycling of brown paper in Norway), working group initiated by the Ministry of Environment.

Ministry of Environment (1995): Innsamling og gjenvinning av plastavfall - arbeidsgrupperapport med forslag til målsettinger og tiltak. (Collection and recycling of plastic waste - report from working group with suggestions for goals and actions.)

Ministry of Finance (1996): *Grønne skatter - en politikk for bedre miljø og høy sysselsetting* (Green taxes - a policy for a better environment and high employment), NOU 1996:9.

MSW Management (1993): Does the Yale University study make sense? MSW Management, January/ February, 34-42.

Naturmiljøet i tall 1994 (Natural environment in figures 1994), Oslo: Universitetsforlaget ,1994.

Pearce, D. W. and R. K. Turner (1993): Marketbased approaches to solid waste management, *Resources, Conservation and Recycling* **8**, 63-90.

Project 88-II (1991): Incentives for action: Designing market-based environmental strategies. A public policy study sponsored by Senator T. E. Wirth, Colorado and Senator J. Heinz, Pennsylvania, Washington D. C.

Rawls (1972): A theory of justice, Oxford: Oxford University Press.

REFORSK (1993): Miljömessige skillnader mellan återvinning/återanvänding och forbränning/ deponering, Stiftelsen REFORSK, FoU nr. 79.

Repetto, R. (1994): Shifting taxes from value added to material inputs, World Resources Institute, paper presented at the International Workshop on "Environmental Taxation, Revenue Recycling and Unemployment, Milan, December 16-17 1994.

Repetto, R., R. Dower, R. Jenkins, and J. Geoghegan (1992): Green fees: How a tax shift can work for the environment and the economy. World Resources Institute, Washington, D.C.

Rogalandsforskning (1996): Differensiering av avfallsgebyrer for produksjonsavfall (Differentiated fees for production waste), RF 96/099.

Rosendahl, K. E. (1998): *Social costs of air pollution and fossil fuel use - a macoreconomic approach*, to be publshed in Social and Economic Studies, Statistics Norway.

Scarlett, L. (1993a): Mandates or incentives? Comparing packaging regulations with user fees for trash collection, Policy study 158, Reason Foundation.

Scarlett, L. (1993b): Recycling costs: Clearing away some smoke, Solid waste & power, July/August.

Schall, J. (1993): Does the Hierarchy Make Sense? MSW Management January/February.

Skumatz, L. A. (1993): Variable rates for municipal solid waste: Implementation, experience, economics and legislation, Policy study 160, Reason Foundation.

Skumatz, L. A. (1996): Nationwide diversion rate study. Quantitative effects of program chioces on recycling and green waste diversion: beyond case studies, Policy study 216, Reason Foundation.

Statens Forurensningstilsyn (1995a): *Miljøkostnader ved avfallshåndtering* (Environmental costs of waste treatment), Report 95/16.

Statens Forurensningstilsyn (1995b): *Kvantifisering av miljøulemper knyttet til luftforurensning* (Quantification of environmental costs of air emissions), Report.

Statistics Norway (1997): *Natural resources and the environment 1997*, Statistical Analyses 17.

Tellus Institute (1991): Disposal fee study, Final report, S0-131.

Tellus Institute (1992): CSG / Tellus Packaging Study, Volume I.

The Economist (1997): America's recyclers. A funny sort of market, October 18th 1997.

Vennemo, H. (1996): The case against discounting the environment, Draft, ECON Centre for Economic Analysis.

Young, J. E. (1995): The sudden new strength of recycling, Word Watch, July/August 1995.

Yu, P.-H., H.-G. Leu and S. H. Lin (1996): Analysis of a municipal recyclable material recycling program, *Resources, Conservation and Recycling* **17**, 1, 47-56.

Appendix

Underlying data

This chapter documents the sources and data used to estimate the costs of air emissions, recycling, incineration and landfill.

Emissions damage estimates

Table A1. Alternative air emission damage estimates, 1995-NKr per tonne emission

	Chosen estimate	Low estimate	High estimate
CO_2	358	38	1 230
CH_4	18156	760	28 279
N_2O	96 660	10 236	331 967
NO_x	49 000		
SO_2	17 000		
Particulate matter	2 020 000		
CO	117		
Dioxines	5 808 000 000 000		
Mercury	211 200 000	1 230 000	211 200 000
Cadmium	1 020 800 000	442 000	1 020 800 000
Lead	282 600 000	263 000	282 600 000
NMVOC	11 000		
PAH	29 900 000		
Toluene	100 000		
Benzene	41 533 482		
Ethyl benzene	72 711 288		
Xylenes	3 635 580		

Sources: For explanation of chosen values: see Bruvoll and Wiig (1996). CO_2 and CH_4: Statens forurensningstilsyn (1995a) and ECON (1995). N_2O: global warming potential in relation to CO_2 = 270 (Naturmiljøet i tall 1994). NO_x and SO_2: ECON (1995). Particulate matter: Rosendahl (1998). CO: Brendemoen, Glomsrød and Aaserud (1992). Dioxines, PAH, toluene: Heijungs et al. (1992), see also ECON (1995). Mercury, cadmium and lead: Statens forurensningstilsyn (1995b) and Heijungs et al. (1992), see also ECON (1995). NMVOC: Statens forurensningstilsyn (1995b). Benzene, ethyl benzene and xylenes: hazard ranking, Tellus (1991), table 6.18.

Recycling

Table A2. Recycling conventional collection costs, $ per ton material collected

	Paper					Plastics			
	News-paper	Corru-gated/craft	Mixed paper	High grade	Other paper	HDPE	PET	Film	Other
Costs $/ton									
Residential	35.76	214.57	107.28	80.46	160.93	459.79	536.42	643.71	459.79
Commercial	28.17	56.35	84.52	31.70	126.78	362.23	422.60	507.12	362.23
Tellus (1991), table 6.4									
Weight	8.0	5.8	8.7	1.0	11.8	0.7	0.3	2.0	3.1
Tellus (1991), table 6.3									
Weighed total									
Residential			126				524		
Commercial			80				413		

Table A3. Recycling collection air emissions

	Paper					Plastics			
	News-paper	Corru-gated/craft	Mixed paper	High grade	Other paper	HDPE	PET	Film	Other
lbs/ton material collected									
CO	0.3655	2.1929	1.0965	0.8224	1.6447	4.6992	5.4824	6.5788	4.6992
NO_x	0.5171	3.1028	1.5514	1.1635	2.3271	6.6488	7.7569	9.3083	6.6488
SO_x	0.0739	0.4433	0.2216	0.1662	0.3324	0.9498	1.1081	1.3298	0.9498
NMVOC	0.1242	0.7453	0.3726	0.2795	0.5590	1.5970	1.8632	2.2358	1.5970
Toluene	0.0022	0.0134	0.0067	0.0050	0.0101	0.0287	0.0335	0.0402	0.0287
Benzene	0.0022	0.0133	0.0067	0.0050	0.0100	0.0286	0.0334	0.0400	0.0286
Ethyl benzene	0.0001	0.0004	0.0002	0.0002	0.0003	0.0010	0.0011	0.0013	0.0010
Xylenes	0.0008	0.0048	0.0024	0.0018	0.0036	0.0102	0.0119	0.0143	0.0102
Tellus (1991), table 5.40									
Weight	8.0	5.8	8.7	1.0	11.8	0.7	0.3	2.0	3.1
Tellus (1991), table 6.3									
tonne emission/ tonne material collected									
CO			0.000588				0.002448		
NO_x			0.000832				0.003663		
SO_x			0.000119				0.000495		
NMVOC			0.000200				0.000832		
Toluene			$3.60*10^{-6}$				$1.50*10^{-5}$		
Benzene			$3.58*10^{-6}$				$1.49*10^{-5}$		
Ethyl benzene			$1.11*10^{-7}$				$5.04*10^{-7}$		
Xylenes			$1.29*10^{-6}$				$5.32*10^{-6}$		
Particulate matter[1]			0.000100				0.000414		

[1] The emissions are estimated on the assumption of the same relationship between the emissions of CO and particulate matter in Norway and US. Norwegian emissions of CO and particulate matter: Table 4.1 in Holtskog and Rypdal (1997)

Table A4. Recycling collection air emissions costs, 1995-NKr per tonne material collected

	Paper	Plastic
CO	0	0
NO_x	41	170
SO_x	2	8
NMVOC	2	9
Toluene	0	1
Benzene	148	619
Ethyl benzene	8	37
Xylenes	5	19
Particulate matter	201	837
Total	408	1 700

Source: Tables A3 and A1.

Table A5. Recycling processing conventional costs, $ per ton material processed

	Paper				Plastics			
	News-paper	Corru-gated/craft	Mixed paper	High grade	HDPE	PET	Film	Other
Costs $/ton								
Residential	13.74		13.74			32.71 (all plastics)		
Commercial	10	-30	10	-60	30	35	50	50
Tellus (1991), table 6.15, 6.16								
Weight	8.0	5.8	8.7	1.0	0.7	0.3	2.0	3.1
Tellus (1991), table 6.3								
Weighed total								
Residential		13				33		
Commercial		-21				47		

Incineration

Table A6. Garbage (incineration and landfill) conventional collection costs, $ per ton material collected

	Paper					Plastics			
	News-paper	Corru-gated/craft	Mixed paper	High grade	Other paper	HDPE	PET	Film	Other
Costs $/ton									
Residential	51.28	89.48	75.00	69.63	81.26	189.41	193.17	110.11	210.97
Commercial	60.78	106.06	88.89	82.53	96.32	224.50	228.96	130.51	250.05
Tellus (1991), table 6.3									
Weight	8.0	5.8	8.7	1.0	11.8	0.7	0.3	2.0	3.1
Tellus (1991), table 6.3									
Weighed total									
Residential			74				175		
Commercial			93				203		

Table A7. Garbage (incineration and landfill) collection air emissions

	Paper					Plastics			
	News-paper	Corru-gated/craft	Mixed paper	High grade	Other paper	HDPE	PET	Film	Other
lbs/ton material									
CO	0.1585	0.2765	0.2318	0.2152	0.2511	0.5853	0.5969	0.3403	0.6519
NO_x	0.2242	0.3912	0.3279	0.3045	0.3553	0.8282	0.8446	0.4814	0.9224
SO_x	0.0320	0.0559	0.0468	0.0435	0.0508	0.1183	0.1207	0.0688	0.1318
NMVOC	0.0539	0.0940	0.0788	0.0731	0.0853	0.1989	0.2029	0.1156	0.2216
Toluene	0.0010	0.0017	0.0014	0.0013	0.0015	0.0036	0.0037	0.0021	0.0040
Benzene	0.0010	0.0017	0.0014	0.0013	0.0015	0.0036	0.0036	0.0021	0.0040
Ethyl benzene	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001
Xylenes	0.0003	0.0006	0.0005	0.0005	0.0006	0.0013	0.0013	0.0007	0.0014
Tellus (1991), table 5.41									
Weight Tellus (1991), table 6.3	8.0	5.8	8.7	1.0	11.8	0.7	0.3	2.0	3.1
tonne emission/ tonne material collected									
CO			0.000104				0.00025		
NO_x			0.000148				0.00035		
SO_x			0.000021				0.00005		
NMVOC			0.000036				0.000084		
Toluene			$6.40*10^{-7}$				$1.50*10^{-6}$		
Benzene			$6.35*10^{-7}$				$1.50*10^{-6}$		
Ethyl benzene			$2.14*10^{-8}$				$5.00*10^{-8}$		
Xylenes			$2.27*10^{-7}$				$5.40*10^{-7}$		
Particulate matter[1]			0.000018				0.000042		

[1] The emissions are estimated on the assumption of the same relationship between the emissions of CO and particulate matter in Norway and US. Norwegian emissions of CO and particulate matter: Table 4.1 in Holtskog and Rypdal (1997).

Table A8. Garbage (incineration and landfill) collection air emissions costs, based on alternative emission cost estimates, 1995-NKr per tonne material incinerated

	Paper	Plastic
CO	0	0
NO_x	7	17
SO_x	0	1
NMVOC	0	1
Toluene	0	0
Benzene	26	62
Ethyl benzene	2	4
Xylenes	1	2
Particulate matter	36	84
Total	73	171

Source: Table A7 and A1.

Table A9. Incineration processing conventional costs, $ per ton material incinerated

	Paper					Plastics			
	News-paper	Corru-gated /craft	Mixed paper	High grade	Other paper	HDPE	PET	Film	Other
Costs $/ton Tellus (1991), table 6.11	25.15	25.53	35.00	32.69	39.84	-6.57	41.00	-6.14	-43.86
Weight Tellus (1991), table 6.3	8.0	5.8	8.7	1.0	11.8	0.7	0.3	2.0	3.1
Weighed total			33				-23		

Table A10. Incineration processing emission costs based on alternative emission cost estimates, 1995-NKr per tonne material incinerated

	Paper			Plastics		
	Chosen	Low	High	Chosen	Low	High
CO_2	0			748	79	2569
CH_4	5	0	8	5	0	8
NO_x	80			70		
SO_x	3			3		
Particulate matter	103			103		
Dioxines	94			94		
Mercury	2	0	2	1	0	1
Cadmium	128	0	128	294	0	294
Lead	3	0	3	3	0	3
NMVOC	0			0		
PAH	3			3		
Other heavy metals	58			52		
Hydr. fluoride/chloride	1			24		
Total	479	341	482	1 400	428	3 224

Sources: ECON (1995) and table A1.

Landfill

Table A11. Landfill processing conventional costs, $ per ton material landfilled

	Paper					Plastics			
	News-paper	Corru-gated/craft	Mixed paper	High grade	Other paper	HDPE	PET	Film	Other
Costs $/ton									
Tellus (1991), table 6.9									
New landfills	32.40	34.48	32.40	32.40	32.40	72.84	72.84	38.77	82.61
Existing landfills	16.37	17.42	16.37	16.37	16.37	36.81	36.81	19.59	41.75
Weight	8.0	5.8	8.7	1.0	11.8	0.7	0.3	2.0	3.1
Tellus (1991), table 6.3									
Weighed total									
New landfills			33				67		
Existing landfills			17				34		

For new landfills we chose Northern California estimates, Northern California uses greater controls than Southern California, because of higher precipitation rates.

Additional Norwegian area costs

Assumptions: Tonne waste per m^3: 0,7. Landfill height: 6 meters. Including the same area for constructions and roads as landfilled area, this implies 0.48 m^2 per tonne waste. The low estimate for area cost is NKr 600 per 1000 m^2, based on an observation on forest property near a landfill site in Oslo. This corresponds to NKr 0 per tonne. The chosen and high estimate NKr 220 000 per 1000 m^2, based on the average price for housing properties nearby Oslo (Akershus), which corresponds to NKr 105 per tonne.

Table A12. Landfill processing emission costs, 1995-NKr per tonne material landfilled

	Paper			Plastics		
	Chosen	Low	High	Chosen	Low	High
CO_2						
50% gas collection				51	5	175
no gas collection				34	4	117
CH_4						
50% gas collection	1 115	47	1 737	323	14	503
no gas collection	2 229	93	3 472	646	27	1 006
Vinyl chloride						
50% gas collection	0			5		
no gas collection	0			11		
NO_x	3			3		
Mercury	1	0	1	1	0	1
Cadmium	1	0	1	1	0	1
Lead	2	0	2	2	0	2
NMVOC	0			0		
Barium	0			0		
Chrome	1			0		
Selen	0			0		
Acetone	41			41		
2-Butanon	149			149		
p-Cresol	2			2		
Tans-1,2-Diclorethyl.	0			0		
Methylcloride	0			0		
Nitrogen	0			0		
Phosphor	0			0		
KOF	4			34		
Total						
50% gas collection	1319	247	1941	583	225	888
no gas collection	2433	294	3676	895	242	1338

Sources: ECON (1995) and table A1.

Tidligere utgitt på emneområdet
Previously issued on the subject

Notater

96/31 Bruvoll, A. and H. Wiig (1996): Konsekvenser av ulike håndteringsmåter for avfall (Consequences of alternative waste treatments)

Reports

95/31 Bruvoll, A. and K. Ibenholt (1995): Norske avfallsmengder etter årtusenskiftet, (Norwegian waste after the millennium)

97/25 Hass, J. (1997): Household recycling rates and solid waste collection fees

97/12 Skogesal, Olav (1997): Avfallsregnskap for Norge - Prinsipper og metoder. Resultater for papir og glass, (Waste accounting for Norway - Principles and methods. Results for paper and glass)

Økonomiske analyser (ØA)

8/95 Bruvoll, A. and K. Ibenholt (1995): Framskrivning av avfallsmengder i Norge

9/96 Bruvoll, A: (1996): Avfallsavgifter. Ein studie av avgifter på emballasjeråvarer (Waste taxation. A study of taxes on packaging virgin materials)

Economic survey (ES)

4/95 Bruvoll, A. and K. Ibenholt (1995): Projections of waste quantities in Norway

Statistical Analyses

17 Statistics Norway (1997): Natural resources and the environment 1997

De sist utgitte publikasjonene i serien Rapporter
Recent publications in the series Reports

Merverdiavgift på 23 prosent kommer i tillegg til prisene i denne oversikten hvis ikke annet er oppgitt

97/3 T. Skjerpen and A.R. Swensen: Forecasting Manufacturing Investment Using Survey Information. 1997. 23s. 80 kr. ISBN 82-537-4374-2

97/4 E. Midtlyng: Arbeidsmiljø i skolen. 1997. 62s. 95 kr. ISBN 82-537-4390-4

97/5 B. Bjørlo og P. Schøning: Resultatkontroll jordbruk 1997: Gjennomføring av tiltak mot forurensninger. 1997. 85s. 95 kr. ISBN 82-537-4397-1

97/6 R.H. Kitterød: Leid hjelp til husarbeid? Bruk av privat rengjøringshjelp 1980-1995. 1997. 59s. 95 kr. ISBN 82-537-4399-8

97/7 S. Holtskog og K. Rypdal: Energibruk og utslipp til luft fra transport i Norge. 1997. 47s. 80 kr. ISBN 82-537-4400-5

97/8 K.O. Oftedal: Arbeidstilbudet fra sykepleiere og leger ved endret studie- og arbeidsmøns-ter. 1997. 27s. 80 kr. ISBN 82-537-4401-3

97/9 A. Bråten og K. Olsen: Ulike metoder for beregning av en indikator for underliggende inflasjon. 1997. 36s. 100 kr inkl. mva. ISBN 82-537-4405-6

97/10 J. Monsrud: Eie og bruk av personbil: Noen utviklingstrekk 1980-1995. 1997. 56s. 115 kr. ISBN 82-537-4411-0

97/11 S.E. Førre: Er store foretak mer forsknings-intensive? En anvendelse av diagnostiske metoder. 1997. 33s. 100 kr inkl. mva. ISBN 82-537-4413-7

97/12 O. Skogesal: Avfallsregnskap for Norge - prinsipper og metoder: Resultater for papir og glass. 1997. 115 kr inkl. mva. ISBN 82-537-4424-2

97/13 J. Lyngstad og K.-M. Roalsø: Langtidsarbeids-lediges inntekter og økonomiske levekår. 1997. 98s. 125 kr inkl. mva. ISBN 82-537-4419-6

97/14 H.M. Teigum: Holdninger til og kunnskap om norsk u-hjelp 1996. 1997. 60s. 75 kr inkl. mva. ISBN 82-537-4425-0

97/15 M. Lund, Ø. Landfald og S. Try: Register-basert evaluering av ordinære arbeids-markedstiltak: Dokumentasjon og analyse. 1997. 46s. 100 kr inkl. mva. ISBN 82-537-4429-3

97/16 E. Holmøy og B. Strøm: Samfunnsøkonomiske kostnader av offentlig ressursbruk og ulike finansieringsformer - beregninger basert på en disaggregert generell likevektsmodell. 1997. 69s. 115 kr inkl. mva. ISBN 82-537-4430-7

97/17 E. Sørensen og I. Seliussen (red.): Samledoku-mentasjon av konjunkturindikatorer i Statistisk sentralbyrå. 1997. 99s. 135 kr inkl. mva. ISBN 82-537-4432-3

97/18 T. Fæhn and L.A. Grünfeld: Commercial Policy, Trade and Competition in the Norwegian Service Industries. 1997. 34s. 100 kr inkl. mva. ISBN 82-537-4437-4

97/19 S.-E. Mamelund, H. Brunborg og T. Noack: Skilsmisser i Norge 1886-1995 for kalenderår og ekteskapskohorter. 1997. 115s. 135 kr inkl. mva. ISBN 82-537-4440-4

97/20 K. Rypdal og B. Tornsjø: Utslipp til luft fra norsk luftfart. 1997. 31s. 100 kr inkl. mva. ISBN 82-537-4449-8

97/21 J. Hass: Investeringer, kostnader og gebyrer i den kommunale avløpssektoren. 1996: Resultater fra undersøkelsen i 1996. 1997. 50s. 115 kr inkl. mva. ISBN 82-537-4453-6

97/22 T. Nygård Evensen og K.Ø. Sørensen: Turismens økonomiske betydning for Norge: Belyst ved nasjonalregnskapets satelittregn-skap for turisme. 1997. 92s. 115 kr inkl. mva. ISBN 82-537-4455-2

97/23 B.K. Wold (ed.): Supply Response in a Gender-Perspective: The Case of Structural Adjustment in Zambia. 1997. 77s. 115 kr inkl. mva. ISBN 82-537-4458-7

97/24 I. Seliussen: Utvalsstandardavvik i detalj-omsetningsindeksen. 1997. 30s. 100 kr inkl. mva. ISBN 82-537-4463-3

97/25 J.L. Hass: Household recycling rates and solid waste collection fees. 1997. 32s. 100 kr inkl. mva. ISBN 82-537-4470-6