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Forecasts Based on a Macroeconomic Model

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Abstract:
Generation of solid waste is closely associated with the use of tangible factor inputs and production levels in the economy. In this paper, we present projections of waste generated in the Norwegian manufacturing industry based on the development in these factors as simulated by a computable general equilibrium model. Over the simulation period, material input becomes relatively cheaper than labour and energy, thereby making it profitable to substitute materials for other factor inputs. This substitution effect is a general equilibrium effect mainly due to technological change. It dominates the direct material saving impact of technological progress in most production sectors. Thus, generated solid waste rises over the simulation period, both in terms of unit produced and per capita. The analysis predicts an increase in generated waste over the period from 1993 to 2010 in the range of 45 - 110 per cent, depending on the type of waste.

Keywords: Solid waste, waste modelling, Norway.

JEL classification: D5, Q29, Q39.

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1. Introduction

Annually, large quantities of solid waste are generated, and this creates environmental problems of many kinds. Ordinary treatment of waste, i.e. waste disposal and incineration, result in emissions of toxic pollutants and greenhouse gases, and seepage from waste disposal sites pollutes ground water and watercourses. The concentration of heavy metals and solvents in solid waste represents serious threat to human health, animals and vegetation. Furthermore, some of the hazardous substances accumulate in the food chain and may therefore lead to environmental problems in the future. Landfills also occupy large areas over long periods. Political actions can be taken to dampen these negative effects. For instance re-use of waste, i.e. recycling, can represent a more efficient use of renewable and non-renewable resources. Thus, improved knowledge concerning potential trends in waste levels and their composition provides important background information for more thorough analysis of waste problems.

There is a growing literature on waste economic costs from waste sites. Mendelsohn et al. (1992) use panel data to analyse the damages associated with waste sites, while Roberts et al (1991) use contingent valuation in a similar analysis. Harrison and Stock (1984) base their analysis on housing price differences to estimate the benefits of cleaning up waste sites. Another strand of the literature consists of studies that evaluate different political tools used in solving waste management problems, see Bernstein (1993), McNiel and Foshee (1992) and Jenkins (1993). Huhtala (1995) examines the optimal rate of recycling, taking into account the environmental costs of landfills. Ayres and Ayres (1993) use material balances to estimate aggregate waste generation and compare this with other estimates on waste residuals. By comparing aggregate inputs and outputs using historical data, their work provides an interesting example of how to use the materials-balance methodology for analyses of waste generation.

Analyses of future developments in waste generation are critical information in the process of planning future waste policy and in determining the long term consequences of the chosen policy. As far as we can see, little work has been done on forecasting waste amounts. Nagelhout et al. (1990) explain future waste generation as proportional to indexes of forecasted production and consumption. In this paper, we use production and material input (raw materials and intermediates) as forecasted by an economic model, to explain future waste generation in manufacturing industries. By using material input we capture both the importance of technological progress and mechanisms of substitution in the production process. Comparing our paper with Nagelhout et al. (1990) we use an economic forecast that is more detailed and we also construct a tool that can be used when analysing different policies concerning waste. Our paper also demonstrates the usefulness of linking projections of waste generation to economic models, as it shows that technological progress may, as it does in the model employed in this paper, induce a substitution towards less labour intensive and more waste intensive production.

Our decision to use a rather detailed, general equilibrium model is partly based on the fact that waste problems are multi-dimensional. A number of waste types, involving many environmental problems, are generated in several different sectors. Ayres and Kneese (1969) point to the fundamental law of conservation of mass and the importance of using general equilibrium models in tracing residual flows. The amount of generated waste is closely connected to the economic system. In evaluating alternative policy tools, a model of the entire economy is required to take these links into account. Furthermore, to capture the environmental effects of structural changes in the economy, a rather disaggregated description of the economy is needed. A general economic model is also essential to estimate the costs associated with waste generation and instruments in waste reducing policy. For instance, imposing extra costs on one sector through environmental regulation or taxation will affect other sectors through price effects and reallocation of resources. Total cost to the society may, therefore, be different from the estimates based on a more partial sectoral study alone.

In this analysis the macroeconomic model MSG-EE is used to estimate changes in key economic variables. These variables are then used to describe the trends in various types of waste up to 2010 (cf. Alfsen et al. (1996) for a description of MSG-EE). The reference path used for the waste projection is approximately the same as used in the Norwegian Long-Term Programme 1994-1997 (Ministry of Finance, 1993), but with a slightly different transport adaptation. Along this path, average technological change in the production sectors is about 1 per cent annually. By using this official forecast we gain higher realism, as it is a natural choice of politics, and the analysis becomes more relevant to the decision makers.

From a material balance argument, we would expect that the solid waste is the difference between the mass of input and the mass of output. Our analysis does not link future waste generation to the difference between material input and output, mainly due to lack of mass-data. The closest proxy, we believe, is therefore to assume proportionality to total material input per sector, and output in some cases. Based on these explanatory factors, we forecast that total generated waste in the manufacturing sectors will increase by 64 per cent from 1993 to 2010.

The paper is organised as follows: Section 2 discusses the methodology, the choice of explanatory factors and addresses the impact of technological progress on the projections of waste. Section 3 summarises the main results. Section 4 discusses the material balance perspective, while section 5 provides conclusions and a summary.

2. Methodology

When projecting possible trends in generated waste levels, choices must be made with regard to explanatory factors. In Bruvoll and Spurkland (1995), generated waste was assumed to be proportional to production in each sector. In this paper we either assume proportionality with production or with the use of material input in the various sectors. The rationale behind this choice is discussed in section 2.1.

All materials that enter the production process, either as raw materials or as intermediates, end up as produced goods or as residuals, e.g. waste or pollutants[1]. One may express this as a trade-off between the quantity of produced goods and the generation of waste. This trade-off may be altered by technological change which makes it possible to increase the number of units produced, without altering the

[1] Material input in MSG-EE is a composite of all goods produced and / or imported in the model. These goods include raw materials, processed goods and services.

amount of generated waste. This reflects a more efficient use of material input, reducing the ratio between waste and production, i.e. the waste intensity.

Relative changes in the factor input prices can also affect the waste intensity. Effects of such changes will manifest themselves both by altered composition of factor use within each industry and through sectoral composition of economic growth. Both types of changes will in turn affect waste quantities.

Thus two factors influence the amount of materials used, and hence the waste generated; technological progress and factor price substitution. The first factor has the direct effect, by definition, of reducing material input used in production per unit of output. The effect of changes in relative prices may work in both directions. However, as we will explain later, technological change systematically reduces the price of materials compared to wages. Thus, along a growth path the substitution effect cannot be considered independent of technological progress and this will tend to increase the material intensity in the production process.

Generally, it is not possible to indicate whether the two above mentioned factors reinforce or oppose each other, and in case of opposing forces, which effect is strongest. However, with the help of a macroeconomic model which takes account of technological change, price substitution and the interaction of the various sectors, a probable trend can be estimated.

2.1. The waste model

The projections of waste generation are based on the assumption that actual waste quantities are proportional to the explanatory factors, and that the factor of proportionality is constant or exogenously given over time. The quantity of waste of type j generated in sector i in year t, $W_{ij}(t)$ is calculated using the formula:

$$(1)\quad W_{ij}(t)=U_{ij}(t)W_{ij}(t_0)d_{ij}(t).$$

$U_{ij}(t)$ is an index for the explanatory variable, either production or material input in sector i generated by MSG-EE. The explanatory variable depends on the waste type j, and the index is 1 in the base year (t_0). The parameter $d_{ij}(t)$ allows for an exogenous shift in the waste level, e.g. capturing the effects of various political measures which influence the generation of waste. $W_{ij}(t_0)$ is obtained from waste statistics at Statistics Norway (Kaurin, 1995). The base year, t_0 , is 1993. The total quantity of waste type j is equal to the sum of waste from all the sectors:

$$(2)\qquad W_j(t)=\sum_i W_{ij}(t).$$

The explanatory variable chosen for each type of waste in each industry is based on a judgement of whether waste generation is best explained by the use of material inputs or by the quantity produced. Paper and cardboard, for instance, are assumed to be material inputs in most industries. Thus material input is chosen as the explanatory factor in all sectors except the sector Manufacture of pulp and paper articles. Here paper and cardboard are assumed to be more closely correlated to the production level, and production is used as explanatory factor[2]. Bruvoll and Ibenholt (1995a) provides further detailed information on the waste model and choice of explanatory variable.

2.2. MSG-EE

MSG-EE is a multi-sectoral equilibrium model in which total production growth is largely determined by technological change, growth in real capital, labour and the supply of raw materials and natural resources. The model has been developed as a tool for analysing the relationship between economic activity, the use of energy and certain environmental aspects (Alfsen et al., 1996). The base year is 1988, and the model is simulated for the period 1988-2030[3].

The model specifies 33 production sectors and 47 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 users (The Ministry of Finance) need for a manageable model. The model describes a general equilibrium, where demand is equal to supply in all markets. Moreover, it requires that individual producers and consumers have no incentive to revise their decisions, and domestic producer prices equal sectoral unit costs in most sectors.

The model does not include an intertemporal theory for saving and consumption decisions, thus variables closing the model are chosen exogenously[4]. Choice of closure rule are one determinant of the outcome of the model.

In most sectors, the factor aggregates labour, capital, energy and materials, are substitutes and constant returns to scale is assumed. The model further assumes exogenous technological and organisational progress. The production functions can be expressed as:

$$(3)\quad Y_i = F_i(K_i, L_i, M_i, U_i, T_i)$$

where Y_i is production in sector i, K_i is the use of real capital excluding transport capital, L_i is the labour used, M_i is material input used in production, U_i is the use of energy excluding transport fuel and T_i represents transport services used. Transport services are not substitutable. Factor inputs are chosen to minimise costs. Material input and real capital are Leontief aggregates of the commodities specified in the model.

The demand for the various factor inputs is expressed as demand per unit produced:

$$(4)\quad zf = Z_f(\varepsilon, PK, PL, PM, PU, PT)$$

[2] For some sectors which contain several types of firms, waste is explained by the use of material input for some of the firms and by production for the others. Based on more detailed historical national account figures, a calculation has been made of each firm's share of total production in the sector. These figures then provide the basis for determining how much sectoral waste is projected by using production trends and how much by using growth in material input.

[3] As the waste statistics used is from 1993, this year is the base year for the waste projections. The simulation period for waste is restricted to 2010.

[4] The closure rule used for the reference path states that the current account and the shadow price of capital should be exogenous.

ε is the rate of technological change, *Pf* is the net purchaser price for factor *f*, *f*=*K,L,M,U,T*. Time series data from the national accounts for the period 1962-1989 have been used to estimate these functions.

Technological change is initially assumed to be Hicks-neutral within each sector, i.e. that the ε parameter is the same for all factor inputs in one and the same sector. Thus, it does not directly influence the relationship between the various factor inputs within a sector. However it affects relative factor prices and thereby, indirectly, changes the composition of the factor inputs in a sector. In the model prices of imports including energy and the interest component in the price of capital are exogenously determined in the world market. The capital goods and material inputs 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 input and capital goods decrease relative to the labour price. This price effect of technological progress causes a substitution from labour input to input of material and capital.

As mentioned, energy prices are determined exogenously, and in the reference path energy becomes relatively more expensive due to a common Nordic electricity market[5].

It turns out that the total use of material input increases faster than total real capital. This indicates that it is easier to substitute material input for production factors which are relatively more expensive than real capital. This is confirmed by table 1, which shows that in general, the shadow elasticities of substitution with respect to energy and labour are higher for materials than for capital.

Table 1. Shadow elasticities of substitution for manufacturing industries in MSG-EE

Production sector	Material vs. energy	Material vs. labour	Capital vs. energy	Capital vs. labour
Manufacture of consumption goods	0.41	1.99	0.33	1.33
Manufacture of intermediate inputs and capital goods	0.96	1.68	0.68	1.02
Manufacture of pulp and paper articles	0.02	1.71	0.33	1.69
Manufacture of industrial chemicals	2.15	2.04	1.25	1.95
Manufacture of metals	0.97	1.04	0.62	1.37
Manufacture of metal products, machinery and equipment	0.67	1.48	0.46	0.80

Source: Holmøy, Nordén and Strøm (1994).

3. Results

The reference path used for the waste projection assumes an average technological change in the production sectors of about 1 per cent annually, i.e. the demand for material input per unit produced falls

[5] As a result of a common Nordic market, the equilibrium price in Nordic countries will determine the price of Norwegian electricity. There was excess capacity in the Norwegian electricity market in the base year, i.e. the price of electricity was so low that expanding capacity was not profitable. A joint Nordic market is assumed to result in an increase in the demand for Norwegian hydropower, and after some time an expansion of capacity will be desired. Higher marginal costs for hydropower development and increased taxation of fossil fuels will, in the long term, result in higher electricity prices (Ministry of Industry and Energy, 1993).

by 1 per cent annually *ceteris paribus*. The effect of price substitution, however, varies between the sectors. Thus the total effect of technological change and price substitution varies.

The increase in total waste from 1994 to 2010 lies largely between 45 and 110 per cent, while total waste generated increases by 64 per cent, see table 2. Generation of all types of waste exclusive of hazardous waste from manufacturing activities are estimated to rise from 3 to 4.9 million tonnes over the period, or by 65 per cent. The growth may be compared to the growth in municipal waste; over the past 15 years, municipal waste amounts increased by nearly 50 per cent[6].

The main waste components by weight are wood waste, food, slaughterhouse and fish waste, paper and cardboard waste and slag and sludge. In total these waste types account for about 70 per cent of total non-hazardous waste generated in the manufacturing industry. Generated hazardous industrial waste rises by 58 per cent. Hazardous waste is composed of oil-contaminated waste, which grows by 68 per cent, other organic waste, which grows by 61 per cent, and inorganic waste, which grows by 56 per cent.

There are considerable differences in the environmental effects caused by the various types of waste. As we have seen, our analysis reveal a wide variation in waste growth. In the process of waste-policy planning, these projections provide important information of future development if no additional policy is implemented.

The waste intensities, WY_j, in table 2 are measures of waste per unit of production, i.e. $WY_j = W_j/Y_j$. The growth in waste intensity, $(W_j(t)/Y_j(t))/(W_j(t_0)/Y_j(t_0))$ equals the ratio between the waste growth and the growth in production; $(W_j(t)/W_j(t_o))/(Y_j(t)/Y_j(t_0))$, where

$$(5)\quad W_j(t)/W_j(t_0) = \frac{1}{\sum_j W_{ij}(t_0)} \sum_j W_{ij}(t_0) U_{ij}(t) d_{ij}(t), \text{ and}$$

$$(6)\quad Y_j(t)/Y_j(t_0) = \frac{1}{\sum_i W_{ij}(t_0)} \sum_i W_{ij}(t_0) Y_i(t)/Y_i(t_0).$$

In (6), the production growth for each sector is weighed by each sector's share of generated waste. Thus, the growth in waste intensity is calculated as:

$$(7)\quad WY_j(t)/WY_j(t_0) = \frac{\sum_i W_{ij}(t_0) U_{ij}(t) d_{ij}(t)}{\sum_i W_{ij}(t_0) Y_i(t)/Y_i(t_0)}.$$

The projections show an increasing waste intensity. Over the simulation period, the average waste intensity growth is 2.3 per cent, indicating that generated waste grows by 2.3 per cent more than does production. For some types of waste the waste intensity grows up to 18 per cent in the simulation period, while it declines only for hazardous waste.

[6] Municipal waste is also correlated with consumption, which in MSG-EE generally grows at a lower rate than material input and production, see Bruvoll and Ibenholt (1995b) for projections of municipal waste.

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Table 2. Generated waste in the manufacturing industry, growth in generated amounts and waste intensity 1993-2010, 1000 tonnes and per cent

	1993	Growth in per cent 1993-2010	
Waste type	Waste quantities (1000 tonnes)	Generated waste	Waste intensity WY
Paper and cardboard	206.8	74	7.6
Plastic	34.1	71	3.8
Glass	55.1	73	3.7
Tyres	0.4	91	8.0
Rubber (excluding tyres)	1.2	89	17.7
Iron and other metals	180.1	78	14.3
Food, slaughterhouse and fish*	446.6	62	0.0
Wood wastes	878.7	61	1.4
Textiles	16.3	104	9.8
Stone, gravel and concrete	142.8	86	6.2
Ash*	17.6	44	0.0
Slag*	272.3	50	0.0
Dust*	73.8	67	0.0
Sludge*	250.2	62	0.0
Chemicals	18.8	111	10.5
Other	214.3	63	2.4
Mixed and unknown	158.2	69	10.5
Total consumption and production waste	2 967.4	65	2.8
Hazardous waste	320.3	58	-2.6
Total	3 287.7	64	2.3

* For these types of waste the growth in waste intensity is 0 per definition, due to projection solely based on the growth in production.

Table 3 shows each sector's share of generated waste in the base year and the growth in material intensity, i.e. demand for material input per unit produced, zM in relation (4), over the simulation period. Generally, the growth in material intensity is positive; despite technological progress the growth in material input is larger than the growth in production. There is considerable variation between the different sectors, but the general conclusion is that the direct material saving effect of technological change is weaker than the price induced substitution effect in most sectors. On the basis of table 3 the average material intensity growth is calculated to be 0.57 per cent for the waste generating sectors[7].

[7] Computed as the weighed average of material intensity growth rates, using the waste shares for each sector as weights.

Table 3. Change in sectoral material input intensity from 1993 to 2010 and sectoral share of base year generated waste for manufacturing industries, per cent

Sector	Growth in material intensity	Share of waste
Manufacture of consumption goods	1.8	18.6
Manufacture of intermediate inputs and capital goods	11.5	28.6
Manufacture of pulp and paper articles	-7.5	23.4
Manufacture of industrial chemicals	-17.8	3.2
Petroleum refining	0.0	4.1
Manufacture of metals	-5.5	15.4
Manufacture of metal products, machinery and equipment	3.1	4.8
Building of ships and oil-platforms	-1.6	2.1

As waste generation primarily is related to the use of material input, the economic development assumed by MSG-EE implies that waste generation rises faster than production in a number of sectors. Technological progress in itself contributes to less waste, for fixed output levels and prices, as it technically allows for less materials per unit produced. However, it turns out that the general equlibrium effects on output levels and factor substitution dominate this direct partial effect and cause an increase in the use of material input.

4. The material balance perspective

According to the material balance perspective, the physical amount of material input in sector i, M_i, winds up as product, Y_i, or waste, W_i. Waste, measured in tonnes, in period t can be computed as:

(8) $W_t = aM_t - bY_t$,

where a and b are weight coefficients[8] for material input, M, and production, Y. Differentiating (7) with respect to time and rearranging yields the waste growth rate:

(9) $\hat{W} = \hat{M} + \frac{1-\lambda}{\lambda}\left(\hat{M} - \hat{Y}\right)$

where $\hat{X} = \frac{\dot{X}}{X}$ for $X = W, M, Y$ and $\lambda = \frac{W}{aM}$.

λ is the fraction, in tonnes, of the material input that will end up as waste. In our model, the growth in waste when material input is the explanatory variable is given by

(10) $\hat{W} = \hat{M}$.

The error in our model compared with the material balance perspective is represented by the term $\frac{1-\lambda}{\lambda}\left(\hat{M} - \hat{Y}\right)$ in (9), and the smaller λ is, the more significant this error will be. In the cases of

[8] Used to calculate weight of a variable measured in value.

increased material intensity, i.e. $\hat{M} > \hat{Y}$, the error will be positive, and the forecasted waste amounts thus will be underestimated. Generally this is the case in our analysis. Adjusting for this error would strengthen the effect of substitution towards use of material input and increase the forecasted waste amounts. Due to lack of data on the sectoral links between the generated waste and the different fractions of the aggregate material input, the effect of this error has not been computed.

5. Conclusions

The increase in generated industrial waste from 1994 to 2010 lies in the range of 45-110 per cent; on average 64 per cent. Despite technological progress, waste growth exceeds production growth and is far higher than estimated growth in domestic product, which is 30 per cent. The growth in waste is mainly explained by the material input growth, thus total growth reflects the 52 per cent material input growth in the simulation period. These results forecast future waste amounts based on the assumption of no additional political actions to those already accounted for in the reference scenario. Environmental effects can be computed on the basis of our analysis. Generally, forecasts are bound to be uncertain. We argue that from a mass balance perspective, the growth in waste per unit of production is underestimated in their study.

Substitution between production factors generally contributes to a higher material intensity. Limited access to labour and energy makes it profitable to substitute these input factors with material inputs, whose relative prices fall. Thus waste generation, which in production processes are closely linked to the use of material input, grows faster than production. Although the direct effect of technological progress is to dampen this effect, technological progress also generates relative price changes that result in substitution toward material input. By using a macroeconomic model, we have been able to take into account the effects of technological change, price substitution and the interaction of various sectors. In addition to providing important information on the effects of a status quo policy, we have presented a tool for simulating forecasts based on alternative political assumptions.

Further works in this area should adjust for the material balance error described in section 4. It would also be interesting to study the effect of disaggregating the material input factor aggregate, and particularly excluding services from the aggregate. Part of the substitutability between the input factors material and labour may be explained by the fact that material is an aggregate of most commodities produced in the economy, including services. On the basis of profit maximisation, firms may choose to reduce their own number of employees, and instead buy corresponding services from other firms. In the national account, and thus in the MSG-EE model, this is recorded as a shift in the use of input factors from labour to material input. The substitution elasticities of the material input in the model might differ from the substitution elasticities reflecting material input fractions correlated to waste. Adjusting forthe service component of the material input may affect the forecasted waste amounts.

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