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Material Accounting in a Macroeconomic Framework

Forecast of waste generated in manufacturing industries in Norway

Abstract:
This paper analyses the generation of waste in production processes, based on the physical law of conservation of mass. By this law, mass going into a production process must equal the mass coming out of the same process. The paper uses this mass balance perspective to refine a previously developed technique for forecasting waste amounts. A macro economic model predicts the use of intermediate inputs and production in monetary units, and by multiplying these variables with weight conversion factors we estimate physical amounts going in and out of production. The difference between input and output, the residual, consists of discharges to land, water and air. We predict a growth in the residuals for manufacturing industries of 83 per cent from 1993 to 2010. The growth is partly explained by an anticipated growth in material intensity.

Keywords: Mass balance, general equilibrium model, waste, forecast.

JEL classification: D5, E17, Q29, Q39.

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1. Introduction

The total flow of materials results in different types of environmental problems, among them the treatment costs connected with solid waste. The definition of when a material becomes waste is vague, but theoretically a material or product will not be considered as waste as long as someone is willing to pay for it. Thus the definition of waste will vary over time, and the concept can be difficult to manage. It is also difficult to get a good estimate over environmental costs from waste, since some wastes are being handled outside satisfying control, e.g. illegal dumping. Statistics over waste is also a rather new area, with gaps in time series and accuracy.

The main purpose with this paper is to describe a method developed to estimate total amounts of and a possible trend in the development of waste (or residuals) generated in production. The production data used concern Norwegian manufacturing industries in 1993, and the forecast is made until year 2010. The most common method used to estimate total amounts of waste generated is to use waste statistics, but in our analysis we have entered the waste concept from a slightly different angle. We have not quantified the waste amounts directly, but have estimated the amount of total mass that needs to be in circulation according to the production process in a given industry. This mass is calculated by using the law of conservation of mass, which states that the total mass is constant. Based on the fact that physical mass cannot be destroyed, it can only alter form, one can construct a mass balance for all production sectors where the mass coming from a production process is the same as the mass put into the process. We have mapped the amounts (in tonnes) of intermediate input and raw materials that enters a production sector and the amounts that comes out of that sector in form of manufactured goods. The difference between input and output must end somewhere. Some of this difference is explained by statistics over emissions to air from production processes. We have defined the remaining, more or less unexplained, mass as *the residuals*. These residuals can not directly be compared with ordinary definitions of waste. We do not aspire to fully explain what the residual consists of and where it eventually ends up, but to estimate its order of magnitude.

The method of mass balance developed in this paper can be regarded as a refinement of an earlier used methodology of waste predictions, see Bruvoll and Ibenholt (1997). In that prediction waste generated in manufacturing industries was linked to the production and/or use of intermediates in production by the use of fixed coefficients. A weakness of that method is the inability to capture changes in the *material intensity* (material use per unit of production) which ought to lead to changed waste amounts. Our method overcomes this weakness by viewing waste as the difference between what goes into a production process and what comes out of it, i.e. calculates waste based on a mass balance, which is one method of incorporating the aspect of material intensity.

The model of mass balance we have developed can also be used to give an overview over the flows of materials in an economy and to analyse such flows. Overviews and analyses can be useful when estimating emissions to air, land and water generated in production processes, and when valuing the damage these emissions can inflict in different recipients. The flows of materials are to a large degree determined by the broad interplay between different agents which characterises economies of today. There is for instance, a large degree of deliveries inside and between the different production sectors. If end consumption of a product increases, then production of that product must rise, and thereby the demand for material also rises. The producers of the intermediate input demands more intermediate input because they have to increase production in order to meet the increase in demand. Thus the initial increase in consumption will have repercussions through most sectors in the economy. When studying the use of mass in an economy it is important to consider this complexity, and we have done this by using the rather disaggregated macro-economic model MSG, see Alfsen, Bye and Holmøy (1996). This model predicts the economic variables needed for our analysis (production and consumption of different commodities). These flows are all measured in monetary units, and an important part in our project has been to transform these monetary flows to physical units, kilogram (kg), to predict the physical amount of residuals in the future.

The principle of mass balance is used for making material accounts for specific materials or products, and most of these take a natural sciences and technical point of view, see e.g. Karlsson (1996) for a general overview, Andersson (1996) for a discussion of carbon flows, and Kandelaars and van den Bergh (1996) for a comparison between PVC and Zinc gutters. Our aim is not to follow any particular material or product, but to analyse the total mass that in the course of one year goes through the different sectors of production. To be able to fulfil such an ambitious project in a reasonable time, we have been forced to use less accurate estimates of mass than is usual in comparable micro-studies. This uncertainty will be transferred to the estimates of the residuals in each sector, and therefore these figures should be interpreted with great care. Nevertheless, the results can indicate sectors with large residuals, which ought to be investigated to reveal amounts of waste which can be of importance for the total social costs of waste treatment.

We have aimed at a general economic and environmental analysis of the activity in society, that is the basis for the residuals generated in the production processes. Ayres and Kneese (1969) early pointed at the importance of mapping all flows of materials in the society, to be able to describe the environmental challenges. Ayres has followed this thought in subsequent studies, for later contributions see e.g., Ayres and Axtell (1994) and Ayres et al. (1996). There has been an increased effort in constructing materials accounts and in incorporating these in the monetary national accounts, see e.g., Bringezu et al. (1996) and de Boer et al. (1996). These material accounts are often centred around a few natural resources and/or different materials. For Germany, physical input-output tables have been developed for all use of resources and products (Stahmer et al. 1997). Due to different handling of resources and sectors, it is difficult to compare the German and Norwegian results. The studies mentioned above are mainly based on physical statistics, whereas our study derives physical amounts out of economic statistics. It is likely that the other studies are more accurate measures of the current physical amounts but our method gives us an opportunity to use a macroeconomic model to predict future physical amounts. As mentioned above the macroeconomic model is constructed based on the input-output structure for the Norwegian economy and it allows us to capture the interconnection between all production sectors, an aspect that can be more or less omitted in a more partial study.

To our knowledge, no one has combined a macroeconomic model with physical data in the same manner as we have done, but there has been some studies going more in detail in specific parts. The use of material balances to account for waste generated has been studied in Ayres and Ayres (1994) and Wolfgang and Ayres (1995). An effort to incorporate material balances directly in a macro-economic model can be found in van den Bergh and Nijkamp (1994). For an early contribution to the use of Input-Output Analysis as a method for forecasting the use of different materials see Leontief et al. (1982).

The analysis is confined to material flows in the production processes. Therefore we can not estimate how and when end products delivered to households and investment sectors turn into waste. In this paper we have chosen to concentrate on the manufacturing industries. The main reason for this limitation is that these sector generates the largest part of the residuals. Another reason is that we wanted to compare our methodology with the one used in earlier predictions of waste (Bruvoll and Ibenholt 1997), and these predictions only concern industrial sectors. We do not model the treatment of waste once it has left the producer, i.e. whether it is being recycled, incinerated or dumped in landfills.

The paper is organised as follows: Chapter 2 discusses the methodology and gives a brief description of the macroeconomic model used. Chapter 3 discusses what the residual may consist of in the different sectors. Chapter 4 describes the result from the forecast, and summarises the main results. Chapter 5 provides conclusions.

2. Methodology

The basis for our predictions of residuals in tonnes is the macroeconomic model MSG-EE (Multi Sectoral Growth Model - Energy and Environment) (Alfsen et al. 1996). This model predicts different economic variables in monetary units, i.e. volumes are measured by indexes denominated in fixed 1988 prices. A time-demanding part of our analysis has been to transform these monetary (or volume) units to the physical unit kilogram, kg. Both the commodity and sector groups in MSG-EE are aggregated, compared to the statistical sources we have used for calculating these factors. We started by calculating conversion factors relating kg to NOK at the most detailed level, and then gradually aggregated them to the level of MSG-EE, see chapter 2.3.2 and appendix a for a more detailed description.

2.1. The Macroeconomic Model

MSG-EE is a general 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. The base year is 1988, and the model is simulated for the period 1988-2030.

The model specifies 33 production sectors and 47 commodities (physical goods and services), reflecting a compromise between the ambition of applying detailed sector information, and the users need for a manageable model. As the model describes a general equilibrium, demand is equal to supply in all markets. Moreover, it requires that individual producers and consumers have no incentives to revise their decisions, and that domestic producer prices equal sectoral unit costs[1].

The model specifies five different input factors: labour, real capital, intermediate input, energy (further divided in electricity and fuels) and transport services. Intermediate input and real capital are Leontief aggregates of the commodities specified in the model. In most sectors, the input factors labour, capital, energy and materials are substitutes, while transport services are not. Factor inputs are chosen to minimise costs, and constant returns to scale is assumed. The model further assumes exogenous technological and organisational progress.

The most common manner to specify technological progress is to use Hicks-neutral progress within each sector, i.e. that the annual efficiency gain is equal 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 version of the model that we have used the annual technological progress is on average 1 per cent.

Equilibrium in each product market implies that total production and import of one commodity equals total use of this commodity as intermediate input, for investment purposes, for private consumption and export. Changes in the demand of one commodity, irrespective of the origin, will affect the production of that commodity and create a chain of changes in demand and supply of both that and other commodities in the model.

Most coefficients in the production structure in MSG-EE are estimated using time series and have additive variables for calibration that reproduces the model's base year, i.e. 1988. Total production and intermediate input in each sector is an aggregate of (up to) 47 commodities, and the composition is determined by fixed coefficients, i.e. the model does not consider possible changes in the composition of commodities being produced and/or used as intermediate input in one sector. We further assume that the conversion factor (kg per NOK) for each commodity produced or used as intermediate input is constant over time. By doing this assumption we can not handle changes in the weight of the aggregated commodities due to for example product development[2]. In real life changes between heavy and light commodities will take place, which may lead to changes in the weight of a (aggregated) commodity.

2.2. Emissions to air

Some of the materials used in production are released as emissions to air through the production process. MSG-EE includes a module which calculates these emissions to air for the nine most important pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_X and N_2O), carbon monoxide (CO), lead (Pb), non-methane volatile organic compounds (NMVOC), particles, carbon dioxide (CO_2) and methane (CH_4) (Brendemoen et al. 1994). The module distinguishes between emissions from three different sources; emissions from stationary combustion, emissions from mobile combustion and emissions from different types of production processes. In our analysis we only include process

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[1] This holds for all industrial sectors in the model, but for the governmental sectors and resource based sectors such as agriculture the use of input factors and/or the output level is given exogenously.

[2] A related problem which our model does not fully capture is products that becomes more expensive due to qualitative changes. In our model this will be registered as quantitative changes, which not necessarily is the case. For instance will two bottle of wines have the same weight regardless of differences in their price. As we become richer it is possible that we will change our demand towards qualitatively better and more expensive, but not heavier, products.

emissions, since these are the only ones directly connected to the use of intermediate input[3]. The method used to calculate emissions makes it possible to handle changes in the emission intensity over time, e.g. due to better technology.

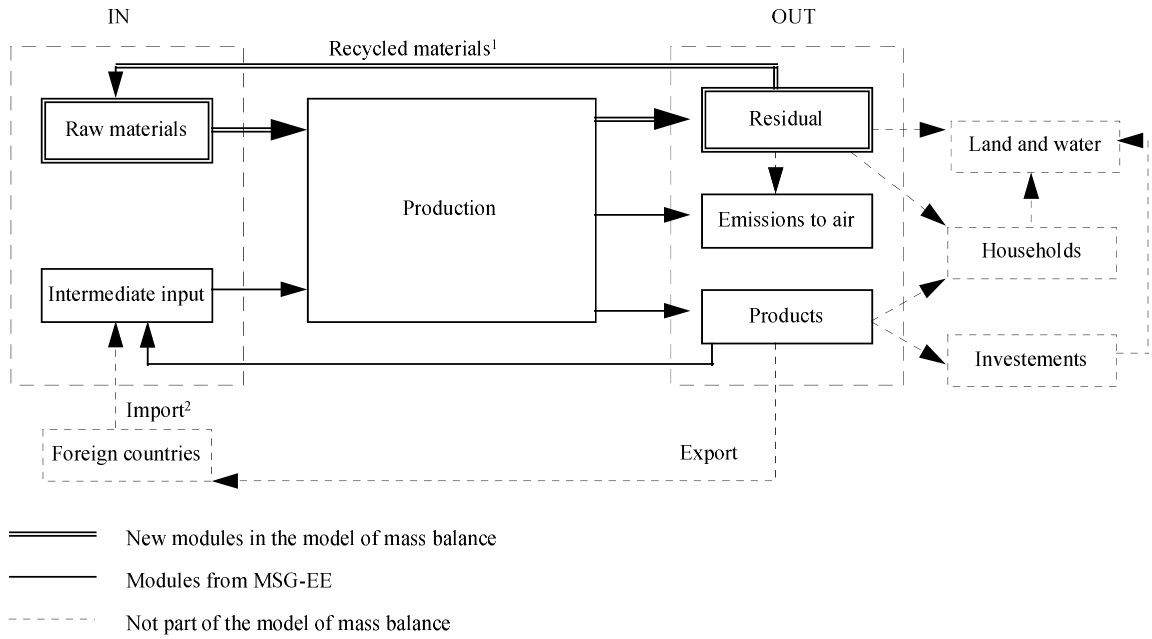
The module calculates the weight of the "final" emission, but most emission consists of a mixture of atoms from the intermediate input and oxygen from air. We have only calculated the weight that comes directly from the intermediate input. For CO_2 only the carbon stems from material use, and carbon constitute 27 percent of the total weight of CO_2, therefore we only account for 27 percent of the mass of the CO_2 emissions calculated in the emission model, in our mass balance.

2.3. The mass balance

Figure 1 gives a schematic presentation of the conceptual model and shows which modules are constructed for our mass balance and which modules belongs to earlier models. On the in-side we account for raw materials (see chapter 2.3.1) and intermediate inputs from the MSG model. The production process is treated like a black box, i.e. we do not account directly for any losses or gains of mass during this process. On the out-side the MSG-model accounts for products and emissions to air, while our model estimates the residual generated in each sector. As can be seen in figure 1, products are delivered to the household sector for private consumption, to production sectors for investment purposes and as export (deliveries as intermediate input is taken care of in the description of the production process). The residual consists of emissions to air not considered in the MSG model, of emissions to land and water, and deliveries to private households, see chapter 3.1 for a description of what these deliveries might consist of. Some of the residuals are being recycled and re-enters the production process as raw materials in our model, see chapter 2.3.1. Residuals are also generated in households and from investment activities (i.e. depreciation) but we do not account for these in our model.

[3] The others are of course important, but since we do not include fossil fuels for energy purposes in the mass entering the production processes, we accordingly must exclude emissions stemming from these activities.

Figure 1. The mass balance model



[1]In the model recycled materials are treated as «free» raw materials, but the residual has not been corrected for this mass. Recycled material makes up approximately 0.5 per cent of total residuals

[2]Imported raw materials are treated like intermediate input in MSG-EE.

2.3.1. Raw material

The input factor intermediate input in MSG-EE consists of all manufactured materials a producer buys from any other producer or imports directly. Many production processes also uses input from natural resources that are not being bought, but extracted. For instance, oil from the North Sea is not intermediate input to the oil producing sector in MSG-EE, since this sector extracts oil from the ground (they pay for the use of the natural resource through taxes etc.). Nevertheless, oil is the most important part of the total weight of the product that this sector produces. To include all materials used in the production processes we have added material groups for oil and other materials treated like oil in MSG-EE. We operate with five groups of raw materials: *crude oil/ natural gas, minerals, net use of water, other raw materials* and *recycled material.* We have chosen to include only net water, i.e. in the balance we account for the difference between water content in input and water content in output. Thereby, if vaporisation of water from intermediate input is larger than the addition of water into the products produced in one sector, this post can be negative. Recycled materials consists of residuals that are being collected and reused or recycled, but we have not subtracted that amount from the estimated residual.

The use of these raw materials are mostly assumed to be proportional to the production in physical units of one particular commodity, produced in own or another sector. For some of the raw materials, especially the use of water, we have instead of production used the amount of one particular intermediate input in own or another sector.

2.3.2. Conversion factors

In MSG-EE, volumes are specified in index terms, denominated in 1988 prices, and to calculate the mass of each of the units, we had to calculate conversion factors that could be linked to the variables in MSG-EE. That way streams and stocks in MSG-EE were transformed from monetary value (NOK) to mass (kg). The commodities in MSG-EE are aggregates of commodities in the National Account (NA), which in turn are aggregates of commodities in individual statistics over different business sectors (e.g. manufacturing statistics) where all or selected enterprises report produced quantities and use of input factors in both monetary and physical amounts. Conversion factors were first calculated at the most detailed level of classification, which is the level used in manufacturing and trade statistics[4]. The data at this level where mainly collected from manufacturing statistics. Due to sensitive information, these statistics are only being published in a more aggregated level than the one we have used, see Statistics Norway (1995). The conversion factors were first aggregated to the level of the National Account, and then to the model level of classification. In the first aggregation the conversion factors for the commodities in the manufacturing statistics where weighted according to their monetary value in relation to the total monetary value for the NA commodity they belong to. For a more detailed description on how this was done, see appendix A.

The conversion factors at the NA level form the basis for calculation of mass of intermediate input and production in each MSG-EE sector. At this level the conversion factors are calculated as:

$$(1) \quad ku_{IJ} = \sum_{i \in I} uw_{iIJ} \cdot (kg / NOK)_i \qquad u = V, X$$

where kV_{IJ} are the conversion factors for intermediate input of MSG-EE commodity I used in MSG-EE sector J, and kX_{IJ} are the conversion factors for production of commodity I in sector J. uw_{iIJ} is the share NA commodity i makes up of MSG-EE commodity I used as intermediate input or produced in MSG-EE sector J. $(kg/NOK)_i$ is the conversion factor for NA commodity i, and this factor is independent of producing sector.

[4] These statistics uses the international commodity classification, the Harmonised System (HS). The level of detail is HS8, that means that each commodity is represented by an 8-digit code (Statistics Norway 1993).

As mentioned above we assume that the conversion factors are constant over time, by doing this we can link them to the variables in the MSG-EE model independent of year. We hereby disregard the fact that product development and/or changes in the composition of commodities can cause the mass of the aggregated commodities to change. A simple test of the development in conversion factors for 22 different (aggregated) commodities and raw materials produced in Norway during the period 1970 to 1992, reveals that for produced goods this factor is more or less stable, whereas the development for raw materials is more varying. The overall trend for raw materials is nevertheless increasing conversion factor, i.e. that the price per kg has decreased, a trend that can be confirmed by studying international commodity markets (IMF, 1998). On the other hand there are developments in manu-facturing industries, specially in electronic manufacturing, towards smaller and lighter products. But this does not necessarily means decreasing conversion factors since there at the same time has been a fall in the real price of this kind of commodities. The overall effect of changes in the conversion factors on the residual can not easily be estimated, since there are forces working in different directions. But since raw materials like minerals constitute a great part of the residuals it is most likely that constant conversion factors underestimate the development in total residuals[5].

2.3.3. Input-output tables

To get a systematic description of the structure of production in each sector and the use of produced commodities and services Input-Output tables are constructed. In the Norwegian National Account, these tables are constructed following the recommendations of UN: «Standard for National Accounting» (SNA), see Fløttum (1996). From the input-output tables one can construct input-output coefficients, and these show the share of input (or production) one commodity constitute of total intermediate input (or production) in one sector. The input-output coefficients used in MSG are all based on the input-output tables in the National Account.

In MSG there are two input-output tables, with corresponding coefficients, that we have used in our analysis: the distribution of intermediate input on different sectors and the distribution of production inside the sectors. As mentioned above (chapter 2.3.1), these tables only specify commodities that can be bought directly from another producer, i.e. the use of raw materials are not included. The tables in MSG have therefore been modified; in the table of use (input) we have added the raw materials that are not treated like produced commodities. In the table of supply (output) we have added emission to air stemming directly from the use of intermediate input, see figure 2.

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[5] The conversion factor for the raw material minerals accounts for gross extraction from the resource. It is common to assume that it is the easiest accessible resources that are being extracted first, i.e. that the mineral content in the rock being extracted is decreasing. By this assumption the difference between net and gross extraction increases over time, and the conversion factor for minerals should then also be increasing.

Figure 2. The input-output tables in the mass balance model

Input	sector 1	...	sector J
commodity 1 . . commodity I	$R1_{11}$ . . $R1_{I1}$	... ...	$R1_{1J}$ . . $R1_{IJ}$
Crude oil/ gas	$R1_{O1}$	...	$R1_{OJ}$
Minerals	$R1_{M1}$	...	$R1_{MJ}$
Net water	$R1_{V1}$	...	$R1_{VJ}$
Other	$R1_{A1}$	...	$R1_{AJ}$
Recycled material	$R1_{R1}$	...	$R1_{RJ}$

Output	sector 1	...	sector J
commodity 1 . . commodity I	$R2_{11}$ . . $R2_{I1}$	... ...	$R2_{1J}$ . . $R2_{IJ}$
Emissions to air	$R2_{L1}$	...	$R2_{LJ}$
Residual	$R2_{RM1}$	...	$R2_{RMJ}$

The law of conservation of masses states that there must be equality between mass going in to MSG-EE sector *J* and mass coming out of that same sector. Using the annotation in figure 2 this law can be formulated as:

$$(2) \quad \sum_k R1_{kJ} = \sum_l R2_{lJ}$$

where k=1,...,I (MSG-EE commodities), O (crude oil and natural gas), M (minerals), V (net water), A (other raw materials), R (recycled materials) and l=1,...,I (MSG-EE commodities), L (emissions to air), RM (residual).

$R1_{kJ}$ and $R2_{kJ}$ are calculated as:

$$(3) \quad R1_{kJ} = kv_{kJ} * \lambda^{V}_{kJ} * V_J$$

and

(4) $R2_{lJ}=kx_{lJ}*\lambda^{X}_{lJ}*X_J$

where kv_{kJ} and kx_{lJ} are the conversion factors for intermediate input of commodity *k* respectively production of commodity *l* in sector *J*. λ is the input-output coefficient for intermediate input of commodity *k* respectively production of commodity *l* in sector *J*. V_J and X_J are total intermediate input and total production in constant prices in sector *J*.

3. Analysis

The residual in each sector of production is determined as the difference between total use of material (intermediate input and raw material) and the sum of total production and emissions to air. The monetary units of these flows are taken from a projection executed by the Ministry of Finance for the Long Term Programme 1994-1997 (St.meld. nr. 4, 1992-1993). The conversion factors which converts the monetary units to mass, have been derived from different sources. There might arise partly big differences between mass in and out that are not reflected in official statistics over solid waste. In some cases the calculations of mass balance will reveal lacking registration in the official statistics, but for other sectors the difference may be caused by doubtful estimates of the conversion factor. For some sectors negative residuals have been calculated, i.e. mass out outweighs mass in. There are several explanations to this, seemingly contradictory result, but mainly the reason lies in inaccurate estimates of conversion factors. Other explanations are mentioned in the description of the sectors, chapter 3.2.

The notion residual in our analysis is not comparable to the notion solid waste in official waste statistics. There are several reasons for this, one obvious is that materials recycled internally in an industry, turn up as residuals in our analysis, while they are not registered as waste in official statistics. Below we will shortly comment on some other reasons[6].

3.1. Parts of the residual

Part of the residuals are substances that flow out with the drain. There are few statistics covering waste water after origin in the form of production sectors, instead these statistics are classified according to geographical areas like municipality boundaries. In 1992 80.000 tonnes of sewage sludge from waste water treatment was registered (Statistics Norway, 1994a), but we have few estimates over

[6] I would like to thank Åse Kaurin and Kristin Rypdal for sharing their knowledge concerning this topic.

amounts leaking directly out in rivers and other waters, without passing any treatment plant. Some particles disappear in diffuse discharges, i.e. as different forms of dust that are not covered in statistics over waste, emissions or waste water. Run-off from agriculture is also part of this problem, but some of this is registered in waste water statistics. One other explanatory factor belonging to this group is corrosion of metals which in certain sectors can constitute a rather large amount. Most likely small parts of the residual in almost all sectors consist of diffuse discharges.

How to treat the weight of packaging materials is problematic, since this weight is not included in the manufacturing statistic, but the weight in trade statistics is inclusive of packaging materials. This means that several sectors can have empty packaging as intermediate input, without any corresponding item out, and in these cases packing will be a part of the residual. On the other hand, the packaging of intermediate input will not be accounted for if these are estimated from manufacturing statistics, and in these cases the residual can be too small. A mapping of the use of packaging material in Norway in 1991 shows a total supply of packaging of 615 thousand tonnes (Matforsk, 1994). Out of this 519 thousand tonnes are net supply of empty packaging, and the rest are import surplus of filled packaging.

Intermediate input in MSG-EE should, in principle, include only commodities with short turnover time (maximum 1 year), i.e. physical investments should not be included. In real life use and storage of intermediate input over one year may exist, thus there is not necessarily an exact match between in and out in one single year. But over time it is likely that stock keeping will even out. In our analysis we have chosen to disregard inventory.

All industrial sectors have some input and production of the commodity *construction*. Due to the way this commodity is accounted for in the NA we calculate the conversion factor separately. The calculation is based on information about wastage of intermediate input in the construction sector, and on the fact that this sector only produces construction commodities. The conversion factor calculated for the construction sector is used for the use and production of the commodity construction in all other sectors. For some sectors this assumption can give erroneous results. It is also questionable whether construction commodities can be classified as intermediate input, in most cases it has more the character of investments and should therefore not be included in our analysis. For all industrial sectors the difference between use and production of this commodity is small compared to the total residuals.

Some of the commodity produced are exported, and according to the argumentation above this export includes some of the residuals. Imported residuals to the sectors of production are accounted for in our mass balance, but residuals from imported goods going directly to the consumers are not included.

For several of these factors there are only minor amounts of mass, and in most cases they can be disregarded. But when evaluating results for individual sectors, some of the explanation of the residual might be found here.

3.2. The residuals

All figures mentioned in this chapter refers to 1993, if not specified different. In this paper we only focus on the industrial sectors though the model is run for all production sectors. For a complete description of all sectors see Ibenholt and Wiig (1998).

MSG-EE operates with eight different industrial sectors: manufacture of consumption goods, manufacture of intermediate inputs and capital goods, manufacture of paper and pulp articles, manufacture of industrial chemicals, petroleum refining, manufacture of metals, manufacture of metal products, machinery and equipment, and building of ships and platforms. Some of these sectors use large amounts of raw materials, especially minerals, whereas other sectors use no raw materials at all. The net content of water varies considerably between the sectors: half of them have negative values for net water content (i.e. more water is withdrawn from the materials included in input than is added to the commodities included in output), one has a positive value and the rest has no added or evaporated water.

Together the industrial sectors generate 69 per cent of all residuals. The manufacture of intermediate inputs and capital goods alone generates 60 per cent of total residuals, mainly since this sector includes mining and quarrying which generates approximately 14 million tonnes of residuals per year, Bergvesenet (1994). The residuals in mining and quarrying is not included in ordinary statistics over waste in manufacturing sectors. A great part of these residuals is left in huge slag heaps or are used as fillings in construction of roads and other construction projects. Nevertheless nearly 6 million tonnes of residuals (18 per cent of total amount) are generated at other types of producers in this sector. Even if we omit residuals from mining and quarrying, our estimates are approximately six times higher than corresponding waste amount calculated in Bruvoll and Ibenholt (1997) for the year 1993. For 5 of the industrial sectors our figures are considerable higher than in Bruvoll and Ibenholt (1997), which may be ascribed to too low registration of waste, that producers treat a lot of waste through recycling (either of the material or the energy content in the residual) within the sector, or to erroneous weight coefficients. A study of material flows in the US automobile industry (Ginley 1994), concluded that 40 per cent of total input into a mid-sized automobile produced in 1990 ended up like residuals (inclusive of residuals from mining). This figure can be compared with the residual percentage for manufacture of intermediate inputs and capital goods which in our study is 49 per cent

For three sectors we calculate negative residuals. In manufacture of pulp and paper articles we assume that the end products are in dry state, such that for each input of 1 kg of commodities from forestry, 0.85 kg of water are evaporated. Thereby we get a negative water content of 3.2 million tonnes in this sector, which gives us a negative residual of 0.52 million tonnes. One can argue if all evaporating from fresh wood should be ascribed to this sector, as part of the evaporating takes place before the timber are delivered from the forestry sector and during transportation.

In the sector producing the commodity *industrial chemicals* we also get a negative residual. The estimated kg/NOK coefficient is decisive for the mass account in this sector. Our estimate for the production of this commodity is 0.57 kg per NOK, while the intermediate input of the same commodity in the production has a weight of 0.56 kg per NOK. Contrary to intuition the price per kg of this commodity falls during the production[7]. This fall may be ascribed to erroneous estimates of the conversion factor, but since the commodities in MSG are aggregates of actual commodities, and the fact that the composition of this aggregate differs according to where the commodity is used or produced, the conversion factor for MSG commodity *I* is not necessarily the same in all production processes, and it can actually be higher for output than for input in one sector.

The sector producing platforms and ships also has a negative residual of 1 million tonnes. For intermediate input and production of *platforms* the same weight coefficient has been used[8].

3.3. Sectoral development in residuals 1993 - 2010

Although it is not possible to compare residuals and waste directly, it is still of interest to compare the *development* in residuals with earlier predictions of waste. Given our assumption that waste constitute

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[7] Normally, the opposite will hold, i.e. that the price per kg for a commodity increases for each step in the production process. This is due to that the price of the commodities coming out of the process shall cover input of both commodities, labour, and other input factors. The weight coefficient we operate with is the inverse of the price per kg, and from this follows that the coefficient intuitively ought to be higher for material input then for the produced commodity.

[8] In MSG the aggregated commodity *platforms* is used as intermediate input and is produced in the sector producing platforms and ships. In the National Account for 1993, on which the conversion factors are based, there is no intermediate input of platforms to this sector. Therefore we have been forced to make a simplification, assuming that the conversion factor for input is equal to the calculated conversion factor for output for this commodity in this sector.

a constant part of the residual, the development in residuals can be transferred to an expected development in waste.

The projections are based on the same path for production and use of intermediate input as has been used in the Long-Term Program for 1994-97 (St.meld. nr. 4, 1992-1993). In this reference path there are no corrections for political actions that might be introduced with the aim to reduce the demand for intermediate input in the future. If the government should implement such actions it is possible to use the development projected in this analysis as a reference path when analysing how effective these actions are.

Using the mass balance method we estimate a total growth in residuals generated in production of 69 per cent from 1988 to 2010. For the period 1993 to 2010, the same period as Bruvoll and Ibenholt (1995) analyse, the growth is 90 per cent. The cause for a greater growth in the period 1993 to 2010 than for the period 1988 to 2010 is a decline in production between 1988 and 1993, that particularly affected some manufacturing industries, facing a contraction of foreign demand. Five out of eight manufacturing industries in MSG-EE had lower production figures in 1993 than in 1988. The decline was especially notable for manufacture of intermediate inputs and capital goods where the production in 1993 was 18 per cent lower than in 1988. Considering that this sector constitutes the largest part of total residual the development in the sector greatly affects overall development in residuals.

Bruvoll and Ibenholt (1997) calculate a growth of 64 per cent for waste generated in manufacturing industries, while the corresponding growth in our analysis is 83 per cent. The difference in growth between these two studies are due to the fact that the residuals are calculated as the difference between the use of intermediate input and the production of material, whereas Bruvoll and Ibenholt (1997) uses a fixed coefficient method, which assumes a fixed relation between waste and production and/or the use of intermediate input in each sector.

The method of fixed coefficients does not handle the fact that different development in intermediate input and production means that the use of intermediate input per produced unit (the material intensity) changes. A change in the material intensity leads to a change in generated waste, assuming that waste in principle is equal to intermediate input minus production. A growing material intensity will increase waste generated, and vice versa. Using a method based on the principle of a mass balance enables one to capture the effects changes in the material intensity have on waste generated.

In the reference path of MSG-EE the use of intermediate input grow relatively more than does production in total, i.e. the material intensity is growing. As the relative price difference between labour and intermediate input grows the demand for intermediate input increases. The reference path has a growth in GDP per year of 1.8 per cent for the period 1990-2010, while man hours, used as a measure of labour, only grow by a factor of 0.21 per cent per year in the same period. Technological progress reduces the prices of produced factors[9], and thus the prices of intermediate input decrease relative to the labour price. This price effect of technological progress causes a substitution from labour input to intermediate input and capital[10]. For the manufacturing industries in general, intermediate input is the factor which is the most easily substitutable with labour. This substitution effect, which causes the use of intermediate input to increase, is strong enough to surpass the opposite scale effect that technological progress generates (i.e. that unit demand for all input factor decreases). Increased material intensity and thus less labour per produced unit can correspond to more error in production and by that increased wastage.

Table 1 summarises the predicted growth in residuals in the industrial sectors from 1993 to 2010. For half of the sectors the growth in input is less than the growth in output. The decreased material intensity in these sectors are most probably due to relatively more expensive intermediate input compared to other input factors and/or limited substitution possibilities. Two of these sectors had a negative residual in 1993 (manufacture of pulp and paper articles and manufacture of industrial chemicals), and these sectors are described in more detail below. The other sectors are petroleum refining and manufacture of metals. In manufacture of metals, the total amount in increases less than the total amount out, 41 compared to 47 per cent, which results in an increase in the residual of 31 per cent from 1993 until 2010. In petroleum refining there is a real decline in the production in addition to the decreased material intensity, and the residual actually declines with 2 per cent from 1993 to 2010. Table 1 also compares the growth in residuals with earlier predictions of the growth of waste generated in the manufacturing sectors. Following equation 7, sectors with a smaller growth in input than in output has a smaller growth in the residual than earlier predicted.

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[9] Technological progress means that, *ceteris paribus*, more commodities can be produced with the same amount of input factors. Thereby the unit cost for each commodity decreases, and the reduction in costs will spill over to intermediate input which consists of produced commodities.

[10] Energy are assumed to become more expensive as a result from a common Nordic market and increased taxation of fossil fuels. The price of real capital is expected to show the smallest relative rise in all sectors, but technological possibilities for substitution between real capital and labour are less than between labour and material input (see also Bruvoll and Ibenholt 1997).

Table 1. Sectoral residuals in 1993, 1000 ton, and growth in intermediate input (including free raw materials), production (including emissions to air), residuals and waste in former prediction[1] from 1993 until 2010, per cent.

Sector		Residuals 1993	Input	Output	Residual	Waste[1]
		1000 ton	growth, %			
15	Manufacture of consumption goods	1 340	64	63	67	63
25	Man. of intermediate inputs & capital goods	19 784	103	94	111	110
34	Manufacture of pulp and paper articles	-518	21	31	104[2]	24
37	Manufacture of industrial chemicals	-4 007	71	106	157[2]	75
40	Petroleum refining	3 499	-2	-1	-2	-2
43	Manufacture of metals	2 826	41	47	31	47
45	Man. of metal products, machinery, equip.	725	134	127	151	134
50	Building of ships and platforms	-1 056	-17	-38	-74[2]	-17
	All industrial sectors	22 593	69	63	83	65

[1]Figures from Bruvoll and Ibenholt (1997)

[2]Sectors with negative residual in 1993, and a positive growth rate means that the residual is declining and vice versa.

A decline in absolute amounts of the residual from 1993 until 2010 are also registered for the sectors manufacture of pulp and paper articles, and manufacture of industrial chemicals, two sectors with negative residuals in 1993. In manufacture of industrial chemicals the use of intermediate input increases by 70 per cent, while the production increases by 107 per cent in the same period. The negative residual was 4 million tonnes in 1993, and it declines to -10 million tonnes in 2010. The negative residual in manufacture of pulp and paper articles are almost doubled during the same period, i.e. it declines from -0.55 million tonnes to -1.06 million tonnes.

The largest contributors of residuals are manufacture of intermediate input and capital goods, in 1993 their contribution was 60 per cent of total residuals, increasing to 67 per cent in 2010. The share of total residuals for petroleum refining falls from 11 percent in 1993 to 5 per cent in 2010 and for manufacture of metals it falls from 11 to 6 per cent during the same period. For the other manufacturing sectors there are only minor changes in their respective share of the total residual.

One interesting result is that the growth in total weight for intermediate input (exclusive of raw materials) in manufacturing industries is less than the growth in total weight for production, 58 per cent compared to 64 per cent. The rather large growth in residuals is explained by the calculated use of raw materials, which grows with 96 per cent, leading to a growth in total weight in with 69 per cent. The growth in total emission to air is 45 per cent, which reduces the growth in total weight out to 63 per cent.

de Bruyn and Opschoor (1997) shows that for many developed countries throughput (or material) intensity are increasing after a period with delinking (reduced intensity), and that instead of the often suggested inverted-U curve aggregate material consumption over time may show an “N-shape”. Reasons behind this relinking (increased intensity) might be that the countries has reached some physical or economic upper bound delimiting the possibility to further increase material efficiency. Our result follows the trend they anticipate in the form of increased material intensity, and in our model the reason is mainly the economic constraint entailed by technological progress and limited labour force.

We have conducted an alternative run of the model, where the figures for those sectors with negative residuals in the first run where altered[11]. In this run total residuals grows by 86 per cent between 1993 and 2010, for the manufacturing industries alone the growth is 81 per cent. For manufacture of industrial chemicals the growth in production is relatively high compared to the growth in intermediate input, and the residual, in the alternative run, will be negative in 2010.

4. Conclusion

We have estimated a total amount of residuals generated in production that exceeds official estimates of waste amounts with almost 250 per cent: 33 million tonnes residuals compared to 14 million tonnes of waste (Norwegian Pollution Control Agency 1995). These figures can not be compared directly since the residuals also consist of sewage sludge, matters being diffused spread, run-off from agriculture etc., and other emissions to air that are not captured in the air emission model. There is no sufficient statistics covering these materials, and figures are difficult to estimate. By assuming that solid waste consists a constant share of the residual it is, nevertheless, possible to compare the growth in residuals with earlier estimated growth rates for solid waste.

Our results show a considerable growth in total residuals from 1993 until 2010, amounting to 90 per cent. In the manufacturing industries, which generates 75 per cent of the total residual, the growth is

[11] The following changes was made: In manufacture of pulp and paper articles we reduced net water amount (which is negative), as a consequence of easing the assumption that all evaporating from fresh wood occurs in this sector. In the first run we assumed that 85 per cent of the weight of total input of forestry products consisted of water that evaporated during the production process of pulp and paper articles, but in the alternative run we reduced the evaporating factor to 60 per cent. As a result the residual in 1993 amounts to 0.4 million tonnes, or 0.09 kg per kg produced. In manufacture of industrial chemicals we have reduced the weight coefficient for production of industrial chemicals by half. The resulting residual in 1993 amounts to 0.4 million tonnes, i.e., 0.08 kg per kg produced. In building of ships and platforms we have reduced the weight

83 per cent, while the corresponding growth in Bruvoll and Ibenholt (1997) is 64 per cent. Bruvoll and Ibenholt (1997) outlines a model for the calculation of solid waste emerging from the principle of mass balances, and out of this it is expected that earlier estimations can be too low. Our analysis investigates this hypothesis by refining the methodology used, and our conclusion supports the hypothesis.

We have made no effort trying to estimate how big the share of waste is in the residuals, and the assumption that this share is constant can, of course, be discussed. Different forms of waste reducing efforts ought to lead to reduced amounts of end treatment of solid waste (incineration or landfill). For instance, does recycling of materials mean that part of the residual is redefined from being "waste" to a product, but nevertheless it will be included in the total mass in circulation. In a longer time perspective increased recycling of materials can contribute to reduced extraction of natural resources and thereby reduced supply of extracted and imported raw materials. A possible extension of our model is to take into consideration increased recycling of materials and other waste reducing efforts.

Our weight estimates are based on special assumptions and statistics from a single year (1993). Changes in the assumptions and/or weight coefficients constructed on time series will probably change our estimates. Constructing conversion factors on time series is relatively resource demanding and has not been regarded for our study. To increase the realism in our model the conversion factors ought to be estimated on the basis of time series of the basic statistics used. Then the risk of temporary variations in the pattern of production affecting the estimates of the factors are avoided. Another related problem is that the information about weight in the statistics being used include various sources of error, including errors at registration, calculation and deviation in units. The current focus on physical accounts as an integrated part of the national accounts[12] will probably contribute to strengthen the quality of the physical data in these statistics.

The coefficients for use of raw material are partly based on discretion, and new knowledge may alter these. For some sectors (like the sector including mining and quarrying) raw materials constitute a large part of total input, and changes in the way we calculate the use of these materials may greatly affect the estimate of generation of residuals in these sectors.

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coefficient for platforms by 30 per cent, and we get a residual amounting to 0.07 million tonnes in 1993, or 0.04 kg per kg produced.

[12] At Statistics Norway NOREEA (Norwegian Economic and Environmental Accounts) are being developed, an environmental account with content after standardised methods for all countries in Europe (Hass and Sørensen, 1997) .

Despite the fact that the residual we estimate lacks a great deal of accuracy, we find the analysis useful as a step towards a more comprehensive model. The method we have used avoids some of the problems that alternative studies of the generation of waste might have. Examples of such problems includes the handling of intra- and interindustry trade and the use of fixed coefficients between production and waste generated. At the same time our analysis reveals difficulties that ought to be analysed more carefully when developing economic models for the use of materials and generation of waste.

The absolute figures in the mass balance can indicate the amount of material that has to be in circulation in the society in order to keep up production. A further development of the mass balance model could be to adjust it to projections over the use of natural resources, which is of especially interest in the ongoing debate on sustainable consumption and production. Hinterberger et al. (1997) proposes that instead of "constant natural capital" as an indicator of sustainable development, flows of materials ought to be used as a decision criterion. They focus on material input, and its importance in environmental macroeconomics. In our definition of intermediate input we do not include all the aspects Hinterberger et al. (1997) consider. However, by for example including materials for energy purposes our model can be adjusted to fit in their definition. It can therefore be a first step towards a model considering sustainable development.

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Appendix A

Calculation of conversion factors

The calculations of the conversion factors required detailed data retrieved directly from manufacturing statistics prepared at Statistics Norway. Statistics at this detailed level are held to be sensitive information, and are not published. Aggregated information for the year 1993 is published as Manufacturing statistics, see Statistics Norway (1995)[13]. In the data we use, production of commodities are registered in both monetary units (NOK) and in physical units (kg), according to the HS8 nomenclature. By dividing the produced amount in NOK with the produced amount in kg, we get the conversion factor for each HS8 commodity. These are then aggregated to National Accounts (NA) level, according to their relative monetary importance (i.e. how much of the total monetary value of the production of one NA commodity each underlying HS8 commodity constitute).

When aggregating from the NA level to the classification level used in MSG-EE we also use data directly retrieved from manufacturing and national account statistics prepared at Statistics Norway. As for manufacturing statistics the National Account is not published at this detailed level, but more aggregated figures are published in Statistics Norway (1996b, 1997). These data show how much each NA sector produces of one NA commodity, and the use of commodities as intermediate input in each sector. Out of this information it is possible to calculate the share, in monetary value, each NA commodity makes up of one MSG-EE commodity produced in one MSG-EE sector. The conversion factor in kg/NOK for each NA commodity was then weighted by this share. By adding up all NA commodities included in the MSG-EE commodity, we got the conversion factor for that MSG-EE commodity produced in one MSG-EE sector. Formally we calculated:

$$(A1) \quad Xw_{iIJ} = \frac{\sum_{j \in J} x_{ij}}{\sum_{i \in I} \sum_{j \in J} x_{ij}}$$

where i = NA commodity, j = NA sector, I = MSG-EE commodity, J = MSG-EE sector.

Xw_{iIJ} is the share NA commodity i makes up of MSG-EE commodity I produced in MSG-EE sector J. x_{ij} is the value of NA commodity i produced in NA sector j.

[13] Other sources are for instance trade statistics (Statistics Norway, 1994b), agricultural statistics (Statistics Norway 1994c) and fishery statistics (Statistics Norway 1996a).

Based on (1) we calculated conversion factors in kg/NOK for MSG-EE commodity *I* produced in MSG-EE sector *J*, kx_{IJ}:

$$(A2) \quad kx_{IJ} = \sum_{i \in I} Xw_{iIJ} \cdot (kg / NOK)_i$$

where kg/NOK_i is the conversion factor for NA commodity *i*, which is independent of producing NA sector.

By using the same method we calculated how much NA commodity *i* makes up of each NOK of MSG-EE commodity *I* used as intermediate input in MSG-EE sector *J*:

$$(A3) \quad Vw_{iIJ} = \frac{\sum_{j \in J} v_{ij}}{\sum_{i \in I} \sum_{j \in J} v_{ij}}$$

where Vw_{iIJ} is the share NA commodity *i* makes up of MSG-EE commodity *I* used as intermediate input in MSG-EE sector *J*. v_{ij} is the value of production of NA commodity *i* used as intermediate input in NA sector *j*.

The conversion factor in kg/NOK for MSG-EE commodity *I* used as intermediate input in MSG-EE sector *J*, kv_{IJ}, was then calculated as:

$$(A4) \quad kv_{IJ} = \sum_{i \in I} Vw_{iIJ} \cdot (kg / NOK)_i$$