Analysing future solid waste generation - Soft linking a model of waste management with a CGE-model for Sweden[Ψ]

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Summary in Swedish

Avfallsmängderna har ökat stadigt under slutet av 1900-talet och i början på 2000-talet. Exempelvis, har uppkomsten av kommunalt avfall per invånare ökat i Nordamerika, OECD och EU15 med 29, 35, respektive 54 procent, från 1980 till 2005[1]. En liknande utveckling har skett också i Sverige, där det kommunala avfallet per invånare ökade med 60 procent under motsvarande period[2]. Även uppkomsten av industriellt avfall ökade i Sverige, med 66 procent, från 1993 till 2006.[3] Under samma period ökade den ekonomiska tillväxten för länderna i Nordamerika, OECD och EU.

MILJÖMÅL FÖR AVFALL

I länder såväl inom som utanför OECD förväntas avfallsmängderna fortsätta att öka fram till 2030, enligt OECD (2008). I OECD-länderna ökade avfallsmängderna i något lägre takt än BNP mellan 2000 och 2005 (en s.k. relativ frikoppling skedde mellan avfallsmängder och BNP-tillväxt). Denna utveckling är dock inte helt säkerställd eftersom det råder stora osäkerheter i det statistiska underlaget om avfallsmängdernas ökningstakt (ibid.). Avfallsprevention återfinns bland de fyra främst prioriterade åtgärderna i EU:s Sjätte miljöhandlingsprogram för att åstadkomma en påtaglig och bestående reduktion av avfallsmängderna inom EU (en s.k. absolut frikoppling mellan uppkomsten av avfall och BNP-tillväxt)[4]. En bestående minskning av avfallsmängderna ska ske också i Sverige. Riksdagen beslutade år 1999, inom ramen för miljökvalitetsmålen, att den totala mängden genererat avfall inte ska öka i framtiden och att den resurs som avfall utgör ska tas till vara i så hög grad som möjligt samtidigt som påverkan på och risker för hälsa och miljö ska minimeras (t ex Miljödepartementet 2006). Detta skulle, under antagande om fortsatt ekonomisk tillväxt, i framtiden innebära en kraftig frikoppling mellan tillkomsten av nya avfallsmängder och ekonomisk tillväxt i Sverige.

METODANSATS

Man har under det senaste årtiondet börjat använda sig av allmänjämviktsmodeller och ekonometriska modeller för att analysera sambandet mellan ekonomisk aktivitet och uppkomsten av avfall och således också frågan om frikoppling mellan dessa båda faktorer. Framtida avfallsmängder belyses i föreliggande studie genom att vi tillämpar ett angreppssätt som integrerar makroekonomi och avfallshantering för att analysera uppkomsten av avfall i fem alternativa scenarier för svensk ekonomi 2006-2030. Uppkomst av avfall är historiskt sett nära förbunden med ekonomisk tillväxt och för att belysa den aspekten skiljer sig de ekonomiska scenarierna åt beträffande tillväxttakten i BNP. För att det ska ske en frikoppling mellan ekonomisk tillväxt och avfallsuppkomst måste uppkomsten av avfall hos företag och hushåll minska i förhållande till deras ekonomiska aktivitet. Vi inriktar oss på denna aspekt genom att låta avfallsintensiteten i företagens produktion och hushållens konsumtion skilja sig åt mellan scenarierna. Genom att överföra resultaten (s.k. mjuk länk) mellan en allmänjämviktsmodell

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1 See http://www.oecd.org/dataoecd/60/46/38106824.xls

2 See http://www.oecd.org/dataoecd/60/46/38106824.xls

3 Beräkningar av Sjöström and Östblom (2009) utifrån data rapporterade av Naturvårdsverket i Swedish EPA (2007) och (2008) och av SCB i Statistics Sweden (2001) om avfall som genereras i svensk tillverkningsindustri.

4 Avfallsprevention (förebyggande av avfall) omfattar åtgärder innan avfallet uppstått som leder till minskning av (1) mängden avfall, (2) avfallets negativa påverkan på hälsa och miljö, och/eller (3) halten av skadliga ämnen i avfallet. Denna studie fokuserar på minskning av mängden avfall.

(EMEC) och en systemteknisk modell över avfallshanteringen (NatWaste) kan vi beakta återverkan mellan avfallsmängder och priser på avfallstjänster (kostnader för avfallshantering) när vi analyserar uppkomsten av framtida avfallsmängder.

RESULTAT

Den ekonomiska tillväxtens betydelse för uppkomsten av icke-farligt avfall framgår tydligt vid en jämförelse av framtida avfallsökningar i våra fem scenarier för Sverige och perioden 2006-2030. I motsats till effekten från ekonomisk tillväxt så motverkar tekniska framsteg, som medför att materialsnålare produktionsprocesser införs, uppkomsten av avfall. På motsvarande sätt motverkas uppkomsten av avfall genom beteendeförändringar hos hushållen i riktning mot ett avfallssnålare konsumtionsmönster.

Scenarioresultaten visar att mängden icke-farligt avfall ökar även vid antaganden om minskande avfallsintensiteter och låg ekonomisk tillväxt. I våra scenarier varierar de totala avfallsmängdernas tillväxt mellan 10 och närmare 100 procent jämfört med 2006. I samtliga scenarier sker en relativ frikoppling mellan ekonomisk tillväxt och avfallsmängder, dvs. de totala avfallsmängderna ökar i långsammare takt än BNP. Absolut frikoppling, då avfallsmängderna stabiliseras eller minskar, inträffar inte i något av scenarierna och således uppnås inte heller det svenska miljökvalitetsmålet om stabiliserade avfallsmängder.

Analysen bygger på att företag och hushåll reagerar på prisökningar för avfallstjänster genom att minska sina bidrag till uppkomsten av avfall. Detta kan företagen göra genom att byta mellan olika avfallsintensiva produktionsfaktorer som material, energi, arbete och kapital i sin produktion av varor och tjänster. Hushållen kan minska sitt avfall genom att välja mellan mer eller mindre avfallsintensiva varor och tjänster. Ju högre kostnader företag och hushåll har för att reducera sitt avfall desto mer måste priset på avfallstjänster öka för att åstadkomma en given minskning i avfallsmängden. En del av prisökningarnas effekt på avfallsuppkomsten fångas emellertid inte upp av vår metodansats. Det är om prisökningarna också medför att företagen investerar i avfallsförebyggande produktionstekniker eller att hushållen förändrar sitt beteende till fördel för avfallssnålare aktiviteter.

Det övergripande intrycket från vår analys är emellertid att kostnaden för att minska avfallsuppkomsten är hög för alla typer av avfall medan kostnaderna för avfallshantering är låga i jämförelse. Detta förhållande medför också att ekonomiska styrmedel som införs i avfallssektorn endast kommer att ha marginell inverkan på uppkomsten av avfall. I detta avseende åstadkoms en större effekt av ekonomiska styrmedel som kopplas direkt till hushållens konsumtion, medan ekonomiska styrmedel som införs i avfallssektorn är mer lämpade för att påverka valet av avfallsbehandling.

SLUTSATSER FÖR FORTSATT FORSKNING

Analyserna har utförts genom att utbyta information mellan en ekonomisk allmänjämviktsmodell (EMEC) och en systemteknisk modell för avfallshantering (NatWaste). Genom att använda en sådan metodansats kan vi vid analys av framtida avfallsmängder ta hänsyn till interaktionen mellan avfallsuppkomst och kostnader för avfallshantering. Dessutom kan vi fånga makroekonomiska effekter såsom BNP-tillväxt och strukturförändringar när vi utformar styrmedel avsedda att förhindra uppkomsten av avfall eller påverka avfallshanteringen i en mer hållbar riktning. Detta gör metodansatsen lämplig för utvärdering av styrmedel som införs på en övergripande ekonomisk nivå (t ex skatt på råvaror och lägre moms på varor av återvunnet material) såväl som för utvärdering av styrmedel inriktade specifikt mot avfallssektorn (t ex miljödifferentierad avfallstaxa och förbud mot förbränning av återvinningsbara material).

Genom att använda de länkade modeller som presenteras här, utvärderas ett antal tänkbara liknande styrmedel inom ramen för forskningsprogrammet Hållbar Avfallshantering (http://www.hallbaravfallshantering.se/) som finansieras med anslag från Naturvårdsverket. Det här presenterade projektet är en del av en integrerad kvantitativ ansats som även omfattar livscykelanalyser av avfallshantering för att utvärdera styrmedlens miljöeffekter (Ljunggren Söderman et al 2009). I en del av forskningsprogrammet görs även kvalitativa utvärderingar av styrmedlens sociala effekter, som i t.ex. Andersson och von Borgstede (2009) och Ewert m.fl. (2009).

Abstract

Parallel to the efforts of the EU to achieve a significant and overall reduction of waste quantities within the EU, the Swedish parliament enacted an environmental quality objective stating that 'the total quantity of waste must not increase …' i.e. an eventual absolute decoupling of waste generation from GDP. The decoupling issue is addressed, in the present paper, by assessing future waste quantities, for a number of economic scenarios of the Swedish economy to 2030 with alternative assumptions about key factors affecting waste generation and waste management costs. We use an integrated top-down/bottom-up approach by linking a CGE-model of the Swedish economy with a systems engineering model of the Swedish waste management system. In this way, we can in more detail consider the interaction between waste generation and waste management costs (waste disposal prices) when assessing future waste quantities.

A relative decoupling of waste generation takes place in all scenarios, i.e. total waste quantities increase at a lower rate than GDP. Absolute decoupling, which require total waste quantities to stabilize or to reduce, does not take place in any of the scenarios. This means that the present Swedish Environmental quality objective of stabilizing waste quantities is not met in any of the scenarios with total waste generation levels of 110 per cent up to nearly 200 per cent of that in 2006.

The overall impression from our analysis is that costs are high for reducing waste generation irrespective of the type of waste reduced. In other words, the waste treatment costs are low compared to the costs for reducing waste. This situation also means that the use of policy instruments, which induce substitution by increasing the price of waste disposal services, will have very small reducing effects on the generation of all types of waste unless the price increase brings about an introduction of waste preventing techniques and affect households in the direction of a less waste intensive behaviour. For example, the policy instruments used must affect the pattern of household consumption pattern more directly, as a differentiation of the value added tax, rather than to be directed towards the waste management sector. Economic policy instruments introduced in the waste management sector are more likely to affect the choice of waste management solutions than prevent waste generation.

Linking a macroeconomic and a systems engineering model for waste management, gives us a tool useful also for capturing the macroeconomic effects, such as GDP growth and structural changes, when designing policy instruments intended to prevent waste generation or take waste management in a more sustainable direction.

JEL Classification Numbers: C68, D20, H23, R48

Key words: general equilibrium model, systems engineering, solid waste, waste management, waste generation, decoupling, EMEC, NatWaste, top-down/bottom-up, waste policy instruments

1. Introduction

The quantities of waste have grown steadily over the past decades. For example, the total quantity of municipal waste per capita increased by 29 per cent in North America, 35 per cent in OECD, and 54 per cent in the EU15 from 1980 to 2005.[5] This development holds also for Sweden, where the per capita municipal waste quantity increased by 60 per cent over the same period.[6] Moreover, waste generation in Swedish manufacturing industries increased by 66 per cent from 1993 to 2006.[7] At the same time, the countries of North America, OECD and EU15 were noted for steadily growing Gross Domestic Products (GDPs).

Waste quantities are expected to increase within the EU, according to the European Environmental Agency (2005), but at a lower rate than GDP from 2020, (i.e. there will be a relative decoupling of waste generation from GDP). Some projections of future waste quantities made for the EU by use of econometric models do indicate relative decoupling of waste from GDP and household consumption (Mazzanti (2008); Mazzanti and Zoboli (2008); Skovgaard et al (2005) and Skovgaard et al. (2007)). The EU Sixth Environment Action Programme lists waste prevention as one of its top four priorities with the objective to achieve a significant and overall reduction of waste quantities (absolute decoupling of waste generation from GDP) within the EU.[8] Parallel to the efforts of the EU to achieve a significant and overall reduction of waste quantities within the EU, the Swedish parliament enacted, as part of 16 environmental quality objectives, the objective 'A good built environment'. As part of the objective, it is stated that 'the total quantity of waste must not increase …' according to the Swedish Environmental council (de Facto 2007) i.e. an eventual absolute decoupling of waste generation from GDP as long as economic growth continues in the future.

During the last decade, attention has been given also to the use of Computable General Equilibrium (CGE) models, besides econometric models, for analysing the relation between economic activity and waste generation, and hence to the decoupling issue. Bruvoll and Ibenholt (1997) use a CGE model to calculate future waste quantities for Norwegian manufacturing, and Ibenholt (2003) uses the same model but extends the analysis by focusing on material balances. Fæhn and Holmøy (2003) use a CGE model to examine the effect of trade liberalisation on solid waste generation and so does Wiebelt (2001) to study the sectoral impacts of a tax on hazardous waste in the South African mining industry. Xie and Saltzman (2000) investigate the effect of a tax on household waste with a CGE model of the Chinese economy. The possibility to decouple generation of solid municipal waste from income growth in the Netherlands by introducing unit-based pricing schemes is analysed within an applied general equilibrium model by Bartelings (2003). Böhringer and Löschel (2006) investigate the coverage of environmental indicators in CGE models and find that four out of eighteen models can tackle decoupling between economic growth and waste generation. Sjöström and Östblom (2009) apply an approach similar to that of Bruvoll and Iben-

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[5] See http://www.oecd.org/dataoecd/60/46/38106824.xls

[6] See http://www.oecd.org/dataoecd/60/46/38106824.xls

[7] This figure is calculated by Sjöström and Östblom (2009) using the data reported by the Swedish EPA (2007), (2008) and Statistics Sweden (2001) on waste generated in Swedish manufacturing.

[8] Waste prevention includes measures before waste generation which leads to a reduction in (1) waste quantities, (2) the negative effects of waste on health and environment, and/or (3) the content of hazardous substances in the waste. This study focuses on the reduction of waste quantities.

holt (1997) to simulate future waste quantities in Sweden. They extend this approach, however, by linking a number of production factors to the generation of several waste types as derived from national waste statistics by Sundqvist et al (2009).

Information on the amount (and composition) of waste generated is indispensable for the planning and operation of waste management systems. Beigl et al. (2008) review 45 waste generation models, published from 1974 and onwards, and reveals a high heterogeneity of the applied models, differing in regional scale, the type of waste streams modelled, the hypothesised independent variables and the modelling method. Among the models are, for example, top-down approaches, such as the studies using CGE models referred to above, which based on a modelling of consumption and production activity offer the possibility of analysing the relation between macroeconomic development and waste generation. Other examples are models with bottom-up approaches in which technical data on treatment options are used for describing the interchanges between different waste types and models using data on demographic and social developments. The latter two are typically used for short- or medium-term waste management planning, such as capacity optimisation when introducing or expanding source separation schemes and biological treatment.

Scientific literature covers many bottom-up approaches with relevance for waste management policy. Life cycle analyses (LCA) of waste management provide information on environmental aspects of e.g. the choice of collection and treatment options. The activity of LCA's on waste management is demonstrated by e.g. the reviews of large numbers of recent LCA's in Cleary (2009) and Winkler and Bilitewski (2007). Other approaches with relevance for waste management policy-making are e.g. operations research methods, multicriteria assessment and expert systems (as pointed out by Shmelev and Powell (2006)), which have been used for demonstrating (either or a combination of) economic, environmental, geographical and social effects of technical changes in waste treatment.

Less common are bottom-up studies explicitly analysing a specific policy instrument. However, the effect of the Swedish tax on waste incineration was analysed by Holmgren and Gebremedhin (2004), Sahlin et al. (2007) and Björklund and Finnveden (2007). The combination of the landfill tax, the producer responsibility of packaging and the, at that time, proposed ban on landfilling of organic and combustible waste in Sweden was analysed by Ljunggren (2000). Ljunggren and Sundberg (2004) analysed e.g. the regional producer responsibility of packaging, landfill tax and EU directive on landfilling in a Swedish region. National and regional targets on material recycling and landfill diversion were analysed for an Irish region by Browne et al. (2009). Policy instruments related to scrap tire recycling were analysed by Chang (2008). A package of policy instruments that could steer waste management towards attaining national environmental targets was proposed by Finnveden et al (2007).

The overall impression is that most efforts have been directed towards predicting the actual quantities of waste, while less attention has been paid to quantifying the economic and/or environmental effects in the waste management sector of the constantly growing waste quantities, and, particularly, analysing the effects of policy instruments for preventing or mitigating the growth of waste.

In the present paper, we assess future quantities of hazardous as well as non hazardous waste, for a reference and four alternative economic scenarios for the Swedish economy using an integrated top-down/bottom-up approach. The analysis presented extends the previous work of Sjöström and Östblom (2009) by soft linking a CGE-model with a systems engineering model for waste management presented by Ljunggren Söderman (2000) for Sweden. By establishing a soft link between the two models (some values of the variables solved for in one model are linked into the data set of the other model in an iterative process), we could in more detail consider the interaction between waste generation and waste disposal prices (waste management costs) when assessing future waste quantities. It was, however, not possible to calculate waste management costs for hazardous waste as treatment processes could be modelled only for non hazardous waste, which account for waste quantities ten times the quantities of hazardous waste in Sweden.

The analysis presented here bears most resemblance to Bruvoll and Ibenholt (1997) by introducing waste intensities into a CGE model for relating future waste generation to the projection of various economic variables. Our analysis, adds to theirs by calculating and using bottom-up information on waste management costs in a CGE model and by exploiting a number of scenarios that differ in the assumptions of key factors affecting waste generation and waste management costs. The economic impact of policy instruments introduced on a macroeconomic level as well as in the in the waste management sector will be analysed in the ongoing research program Towards Sustainable waste Management about sustainable future waste management in Sweden. The economic assessment of policy instruments is part of an integrated quantitative concept, which also includes life cycle assessments for evaluating environmental effects (Ljunggren Söderman et al 2009). As part of the research programme, qualitative assessments of the social effects of policy instruments are also performed (for example Andersson and von Borgstede (2009) and Ewert et al. (2009)).

The rest of the paper is organized as follows. Section 2 describes the CGE-model EMEC and the waste management model NatWaste and how the models interact in the present analysis. Thereafter, in Section 3, benchmark data and scenario assumptions are presented. In Section 4, the results are reported and finally Section 5 contains some concluding remarks. A thorough presentation of all the results is given in the tables of Appendix A. Appendices B and C give classifications and definitions of sectors, commodities and waste fractions of the models.

2. Method

The prices of waste disposal services are affecting the waste generation of firms and households. The price of services provided by society for waste disposal is determined by waste treatment costs including the costs induced by the policy instruments directed towards the waste management sector. Changes in the waste treatment costs affect the behaviour of firms and household and, thus, economic growth, structural changes and income distribution. These economic effects in turn could decrease or increase the generation of wastes. To link fully, the firms' and households' adjustments of production and consumption to changes in waste treatment costs, in some detail, a number of waste management options should have to be integrated into the framework of a computable general equilibrium model (CGE-model) of the economy. Instead, we soft link a top-down CGE model and bottom-up systems engineering model for waste management, which focus on detailed analysis of technological options and potentials for technical changes in the waste management sector. Both are existing peer-reviewed models, which means that we avoid repeating earlier work and benefit from initial quality assurance to the efforts (Wene 1996). Furthermore, soft linking provides a high variety tool while maintaining sufficient practicality without loosing transparency. Soft linking also offers a significant benefit in bringing together the two academic disciplines of macroeconomic modelling and systems analysis of waste management. The general setting of the integration between the CGE-model EMEC and the systems engineering model for waste management NatWaste is presented in the following paragraphs.

The waste management model NatWaste

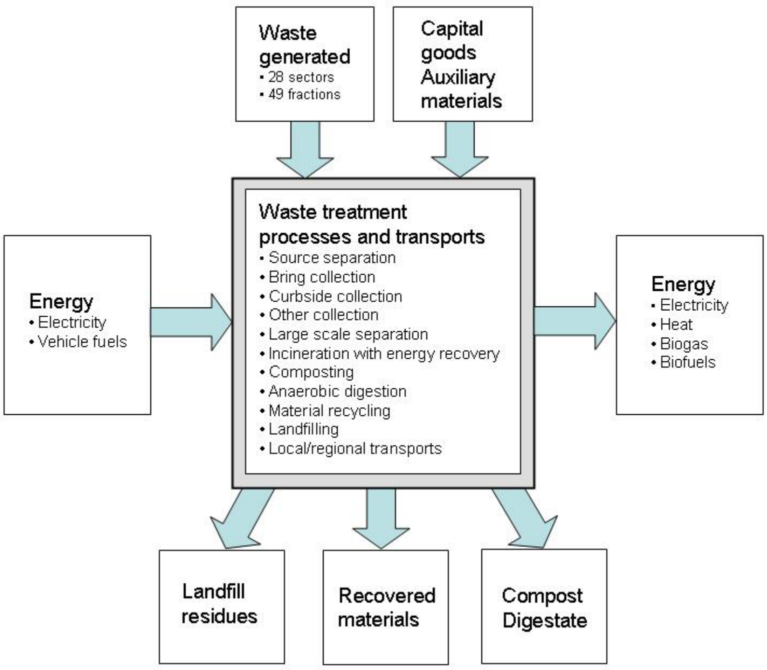
NatWaste is a systems engineering model for strategic planning of national waste management systems (Ljunggren 2000). NatWaste focuses on detailed analysis of technological options and potentials for technical changes in the waste sector on a national level and has been used to, e.g., assess the consequences of a tax and landfilling bans in Sweden (Ljunggren 2000) and, in addition, efforts to promote biological treatment and material recovery (Ljunggren Söderman 2003). Results from NatWaste specify economically optimal capacities of technical waste management options, the quantities of waste and material treated in the various options and the energy turnover[9].

Based on cost-minimisation, NatWaste calculates the cost-effective mix of waste-treatment methods, in particular in a context of scenario analysis. The scope includes the so-called waste management system (Figure 1). Waste of a certain quantity and composition enters the system at the point where it is collected from the waste generators (i.e. households, industries and trade). The waste is treated in the system, usually through a combination of treatment methods. Finally, from the system exit (1) recovered materials to be absorbed by the markets for materials; (2) recovered compost or anaerobic digestion residues to be absorbed by the market for e.g. fertilisers; and (3) waste to be stored long-term in a landfill. Auxiliary materials (additives) are

[9] Originally, NatWaste calculated a limited number of emissions to air and residual content of harmful substances in the waste: fossil carbon dioxide, methane, nitrous oxides, sulphur oxides, carbon monoxide and four heavy metals e.g. (Ljunggren 2000). In the present study, however, this feature of NatWaste is not used since the study is part of an integrated concept in which life cycle analysis will be used for evaluating environmental impacts. LCA offers the possibility of a broader analysis of environmental impacts than NatWaste.

supplied for running the system. If investments in new equipment are made, capital goods are supplied to the system. Auxiliary energy in the form of electricity and fuels is supplied for running the system. Energy can be recovered from the system in the form of heat, electricity and biogas, to be absorbed by the markets for energy carriers. The waste management system is linked to its environment by economic information, i.e. prices, on the material and energy flows[10] that are transferred across its system boundary. In NatWaste, the national waste management system is described as a number of coupled generalised municipal waste management systems. For analysis of Swedish national waste management, ten coupled generalised municipal waste management systems are used. These ten systems are distinguished from each other through four key factors: small/large size, existance/non-existance of district-heating system, existance/non-existance of waste incineration, and existance/non-existance of landfill. Each of the generalised systems represents one, or many, real Swedish municipalities or, in other words, all Swedish municipalities are represented in the model.

Figure 1 Scope of the waste management system in *NatWaste*



NatWaste is a one-period linear programming model. This means that the model (1) analyses the waste management system for a static period (normally one year); (2) describes the system in linear equations; (3) optimises the system for a defined objective function, and (4) can include a number of external constraints, such as process requirements, emission constraints and requirements for recovery. The model is implemented in GAMS (General Algebraic Modelling System). The optimisation objective applied in this study is minimisation of the total annualised cost for the national waste management system in terms of entrepreneur costs including internalised environmental costs such as taxes and fees. The cost function includes variable costs for waste treatment, for local and regional transportation of waste, for auxiliary energy and materials, annualised investment costs for new technologies and expanded waste treatment capacity, and revenues for recovered items. Capital costs for investments

[10] Prices of materials and energy also includes costs for labour and transports.

already made are not included (since these are regarded as sunk costs). Technological development of specific processes until the final year of the analysis 2030 is not explicitly considered. However, as a guiding principle, data representing best current commercially available technology (BAT) in a Swedish perspective is used.

The CGE-model EMEC

EMEC is a computable general equilibrium (CGE) model of the Swedish economy developed and maintained by the National Institute of Economic Research (NIER) for analysis of the interaction between the economy and the environment.[11] The model is implemented in GAMS.

EMEC is a static CGE-model with 26 industries and 33 composite commodities and a public sector producing a single commodity. Produced goods and services are exported and used together with imports to create composite commodities for domestic use. Composite commodities are used as inputs by industries and for capital formation. In addition, households consume composite commodities and there are 26 consumer commodities. Production requires primary factors (two kinds of labour and capital) as well as inputs of materials, transports and energy. Households maximize utility subject to an income restriction, firms maximizes profit subject to resources restrictions, disposal of public services are subject to a budget constraint and the foreign sector's import and export activities are governed by an exogenously given trade balance.

The supply of each type of labour is exogenous for the economy as a whole, while capital is supplied to the economy at a given price. All factors can move freely between domestic sectors. Perfect competition and no economies of scale in production are assumed for all markets. The small country assumption is adopted for tradable goods and the problem of overspecialization is handled by the Armington assumption. We assume Sweden's products to have small shares of total demand in world markets and, therefore, any quantity of exported goods must be sold at given world market prices. The model runs with exogenous interest rate and an exogenous ratio of the current account is used as closure rule.

Households are distributed into six subgroups by disposal income and by place of residence. The use of energy by firms or households is subject to an energy tax and pollution taxes. Consumer goods are also subject to a value-added tax as well as other indirect taxes. The use of labour is subject to social security fees and households pay income tax on labour income. Firms and households react on prices, including taxes, and adjust their mix of inputs or their bundle of consumer goods by substituting away from the relatively dearer input or good.

The representative firm is assumed to choose an optimal mix of two types of labour and an optimal mix of energy in three stages. The firm, then, decides upon the mix of labour and physical capital in the creation of value added as well as the mix of energy and material in the creation of energy-material input. The various outputs and inputs must be transported, and the firm chooses an optimal transport solution (which allows for the use of several transport modes) in two steps. An optimal mix of value

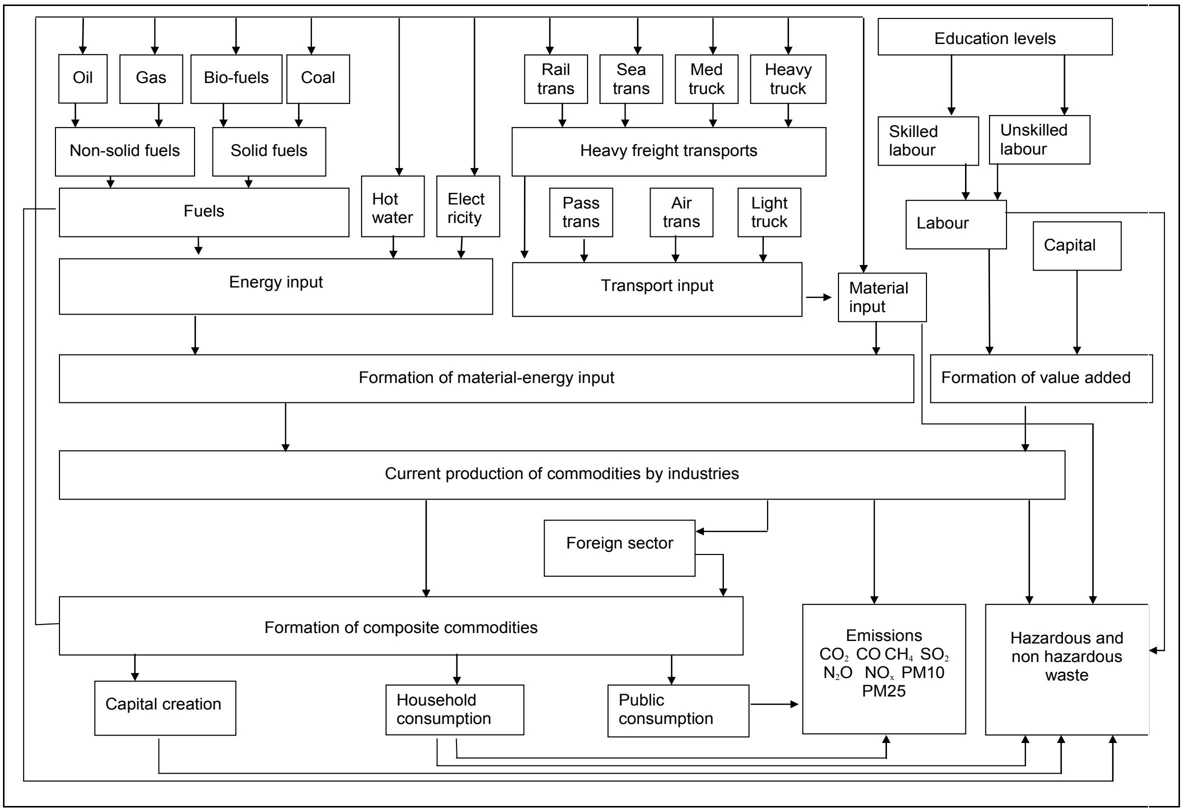
[11] The model was used for the first time in the Swedish Medium Term survey (MTS) of 1999/2000 (reported in SOU 2000:7) but also in the MTS of 2003/04 (reported in SOU 2004:19). It was used also for analysing the economic implications of the Kyoto agreement on CO2 restrictions (reported in SOU 2000:23 and by Nilsson (2002)), for analysis of economic effects on Sweden of EU's system of emission trading (reported in SOU 2005:10, SOU 2003:60 and by Östblom (2003a), (2003b), (2004a)) and for analysis of Sweden's climate strategy (kontrollstation 2004) reported in (Sveriges klimatstrategi) and by Östblom (2004b). Sulphur abatement cost functions were introduced in the model by Östblom (2002). Also, a feedback effect on health and labour productivity of nitrogen oxide pollution was introduced by Östblom and Samakovlis (2007).

added and energy-material input is chosen at the highest level, to produce the firm's output. Another kind of substitution relates to goods of the same classification. Domestic goods are non-perfect substitutes for foreign goods in domestic as well as foreign use; i.e. in imports as well as in exports.

Besides households and firms, the model economy includes also a public sector and a foreign sector. Public goods and services are produced by a single government agent and consumed by households and firms. The government has income from taxes on labour income, consumption and production, respectively.

To capture the effects on waste generation of various future economic scenarios within a CGE framework, the waste generation of households and firms due to their economic activities must be modelled with the option of adjusting to changes in the costs of using waste generating inputs or outputs. The economic model EMEC exhibits such adjustment mechanisms when households and firms choose among a number of waste generating and non-waste generating inputs and outputs.

Figure 2 Flows of commodities, factors, emissions and wastes in *EMEC**



*The arrows indicate the direction of flows.

The waste flows in the economy, depicted in Figure 2 for the model EMEC together with other flows of the economy, relate to production and consumption of commodities, and thus economic activity generates waste by the input use in production and by the households' use of outputs. Production demands inputs of materials and energy, which are substitutes for the inputs labour and capital in the model. Firms are cost minimising in the choice of labour, capital, energy, materials and transports for producing outputs. Materials, labour and capital are all waste generating inputs but to various degrees. Thus, the substitutions between these inputs as well as productivity changes in the use of the inputs affect the waste flows of firms. Households' waste flows are affected by the consumption of goods and services. The firm's production function, the household's demand function and the waste generating procedures of firms and households are presented in the following sections.

The interaction between NatWaste and EMEC

The top-down CGE model EMEC and the bottom-up systems engineering model for waste management NatWaste are soft linked in the aspect that the values of some variables solved for in one model are transferred into the data set of the other model in an iterative process. To give a consistent and transparent picture of this model interaction, the models are presented, here, within a common general equilibrium framework. The waste management model will have the role of feeding the CGE-model with the prices, or unit costs, of waste disposal services. All other prices of commodities and production factors are given by the solution of the CGE-model and are linked to the waste management model. Firms and households react by reducing waste generation when the prices of waste disposal services increase, and thus the CGE-model will have the role of returning the wastes generated in the economy given the prices of waste disposal services. The convergence of this iterative process is granted, as the unit costs of waste treatment will not increase when the generation of waste decreases.

The prices of waste disposal services, solved for in the waste management model, are transferred to the CGE-model as a waste tax paid by firms and households. This is done for model technical reasons, and to avoid a resource drain from the economy, we introduce a corresponding lump sum transfer to households in the CGE-model. Firms' and households' expenditures on waste disposal services correspond to revenues produced in the waste management system and thus outside the CGE-model. The advantage of using a detailed waste management model for generating the prices (or tax) of waste disposal services is that the effect of policy instruments directed toward various processes of waste treatment is transformed into the prices (or tax) of waste disposal services used in the CGE-model. The recovered materials and energy carriers produced by the waste management system, besides the waste disposal services, are regarded as integrated in the corresponding aggregated inputs used by the production sectors of the CGE-model. The production of recovered materials and energy carriers by the waste management system affect its use of net inputs and thus the prices of waste disposal services.

The data on waste fractions interchanged between NatWaste and EMEC, complies with the waste types defined in the European Waste Statistics Directive (EWC-Stat) (EU 2002). The EWC waste fractions, however, are too aggregated for a meaningful analysis of waste management options performed with NatWaste. The EWC-Stat waste fractions, therefore, are disaggregated into sub fractions to fit the waste management options in NatWaste. The waste fractions interchanged between the models are presented in Appendix C.

WASTE GENERATING PRODUCTION SECTORS

All the production sectors, which generate various types of waste and produce goods and services, Q^I, by the means of labour L, capital, K, various energy carriers, E, materials, M, and transports, T are within the CGE-model (EMEC). A waste generating sector j produces goods and services in the proportions given by matrix, Ω^I , and have the following non-linear production function:

$$\left(\sum_i Q_i^I \cdot \Omega_{j,i}^I\right) = F_j\left(K_j, L_j, M_j, E_j, T_j\right) \qquad 1$$

The k types of waste are, here, connected to the production of goods and services in five different ways by waste coefficients $d_{j,k}^{(\cdot)}$ for production sector j. Waste is generated by incomplete absorption of material inputs (M) in the production process, by $d_{j,k}^M$, or is directly related to the goods and services (Q^I) produced, by $d_{j,k}^Q$. Waste is also generated by fuel combustion (E), by $d_{j,k}^E$, the disposal of scrapped capital equipment (K), by $d_{j,k}^K$, and due to the staff members' garbage (L), by $d_{j,k}^L$.[12] Transports (T) are, here a production factor not generating waste as we deal with solid waste in the present context and thus emissions to the air will not be classified as waste.

$$W_{j,k}^F = d_{j,k}^M \cdot M_j + d_{j,k}^L \cdot L_j + d_{j,k}^K \cdot K_j + d_{j,k}^E \cdot E_j + d_{j,k}^Q \cdot Q_j^I \qquad 2$$

Firms maximize profits subject to the production function. The condition of no profits in production states that revenue equals costs of production with output price PQ^I and the factor prices PK, PL, PE, PM and PT. However, the sectors generating waste must pay the price PQ^{II}, to dispose of the waste, as we do not allow for a free disposal of waste. Revenue, thus, must equal production cost and waste disposal cost:

$$\begin{aligned}&\sum_i PQ_i^I \cdot Q_i^I \cdot \Omega_{j,i}^I = \\ &PK_j \cdot K_j + PL_j \cdot L_j + PM_j \cdot M_j + PE_j \cdot E_j + PT_j \cdot T_j + \sum_k PQ_k^{II} \cdot W_{j,k}^F\end{aligned} \qquad 3$$

HOUSEHOLDS

Households are also within the CGE-model. Households maximize the utility of consumption, taking the market price PHC_{pr} for consuming the quantity HC_{pr} of the good pr as given, subject to the budget constraint stating that the expenditures on all goods and services cannot exceed disposable income, i.e. labour income $PL \cdot LTOT$, capital income $PK \cdot K$, transfer incomes TR, less savings S.

$$\sum_{pr} PHC_{pr} \cdot HC_{pr} \leq PL \cdot LTOT + PK \cdot K + TR - S \qquad 4$$

The household's demand for various consumer goods and services HC_{pr}, then, is a function of relative prices PHC_{pr} and the total consumption expenditures PKL.[13]

Households' demand:

[12] The waste coefficients could change due to technological progress. Especially, in the case of materials this would affect the material productivity of production processes. This rebound effect, however, is not modelled in the present approach, although the scenarios presented in Section 3 will differ according to assumed changes in waste coefficients.

[13] The prices *PHC* are related to the prices PQ^I of produced goods and services by transforming the composite prices for goods and services produced or imported. By the same kind of transformations, the consumer goods and services *HC* are related to the produced goods and services Q^I.

$$HC_{pr} = \psi_{pr}(PHC_{pr}, PKL) \qquad pr = 1,...,n \qquad 5$$

Households are generating waste by their disposal of goods and services consumed. We assume household waste type W_k^H to be generated in relation to the demand of various goods and services HC_{pr}. The waste intensities of households $d_{k,pr}^H$ could increase as well as decrease over time due to a changed behaviour. Therefore, we allow also for the demand of disposal services HC_5 to have an influence on households' waste generation by a factor δ_{pr}.[14]

Generation of waste type *k* by households:

$$W_k^H = \sum_{pr} d_{k,pr}^H \cdot \delta_{pr} \cdot HC_{pr} \qquad 6$$

As there is no free disposal of wastes, the budget constraint is modified to include also the expenditures on waste disposal $\sum_k PQ_k^{II} \cdot W_k^H$ on the left hand side. Transfer incomes on the right hand side must be complemented with the lump sum transfer of total expenditures on waste disposal TR^W to avoid a resource drain from the economy, as was discussed in a preceding paragraph. The budget constraint in (4) will now read:

$$\sum_{pr} PHC_{pr} \cdot HC_{pr} + \sum_k PQ_k^{II} \cdot W_k^H \le PL \cdot LTOT + PK \cdot K + TR + TR^W - S \qquad 7$$

THE WASTE MANAGEMENT SECTOR

The waste management sector, represented in some details in the systems engineering model (NatWaste), is described as a cost minimising system that processes given quantities of waste fractions generated in the rest of the economy. A number of inputs are used by the system, which also supplies recovered materials and recovered energy carriers. To harmonize with the representation of waste types and waste disposal services in preceding paragraphs, the processing of waste fractions is, here, looked upon as a supply of disposal services to the rest of the economy. A waste treatment process handles several waste fractions and thus produces several waste disposal services.

The waste management system's supply of recovered materials and energy carriers are in the present context treated as net inputs in the supply of disposal services and, thus, affect the prices of these services. The prices of disposal services transferred to the CGE-model normalize to unity for the base year as for all prices within the general equilibrium framework. This means that an increased supply of recovered materials or

[14] The waste generation is modified to be in proportion to both HC_{pr} and HC_5 instead of being in proportion only to HC_{pr} by introducing the geometric mean $\delta_{pr} = \left(\frac{HC_5}{HC_5^0} \cdot \frac{HC_{pr}^0}{HC_{pr}} \right)^{1/2}$ and we will have $\left(\frac{HC_5}{HC_5^0} \cdot \frac{HC_{pr}}{HC_{pr}^0} \right)^{1/2} \cdot HC_{pr}^0$ instead of $\frac{HC_{pr}}{HC_{pr}^0} \cdot HC_{pr}^0$ in equation 6 . Variable values at the base year are denoted HC_5^0 and HC_{pr}^0.

energy carriers by the waste management system will act as a cost reduction and reduce the price of waste disposal services supplied to other sectors of the economy.

The waste management sector uses the same kind of inputs as the waste generating sectors for producing waste disposal services Q^{II} but the input of energy carriers and materials could be negative as the waste management system produces recovered materials and energy carriers besides the waste disposal services. The waste management sector is assumed to have the following linear production function for a waste treatment process, *j*, where Ω^{II} is a mapping of disposal services, *k*, to processes:

$$\sum_k Q_k^{II} \cdot \Omega_{j,k}^{II} = G_j\left(K_j, L_j, M_j, E_j, T_j\right) \qquad 8$$

The objective of the waste management system is to minimise total costs or likewise maximise profits subject to the production function G_j. We assume waste taxes t_j to be levied on treatment processes, *j*, and not on disposal services *k*.

$$\mathbf{Max} \sum_j \left(1 - t_j\right) \cdot \sum_k PQ_k^{II} \cdot Q_j^{II} \cdot \Omega_{j,k}^{II} - PK_j \cdot K_j - PL_j \cdot L_j - PM_j \cdot M_j - PE_j \cdot E_j - PT_j \cdot T_j \qquad 9$$

CLOSURE RULE

Waste disposal services are supplied by the waste management sector modelled in NatWaste, whereas the waste generating firms and households modelled in EMEC demand these services. As a closure rule for the market of disposal services, we introduce the condition that demand must equal supply at positive prices of disposal services as stated in equation 10. The expenditures on waste disposal services by firms and households represented in EMEC correspond to revenues of the waste management sector represented in NatWaste. To override this gap when solving the general equilibrium system we let households receive a lump-sum income transfer equal to the expenditures on disposal services as stated by equation 11.

Firms and households cannot dispose of waste type *k* without being in possession of a corresponding disposal service with a positive price.

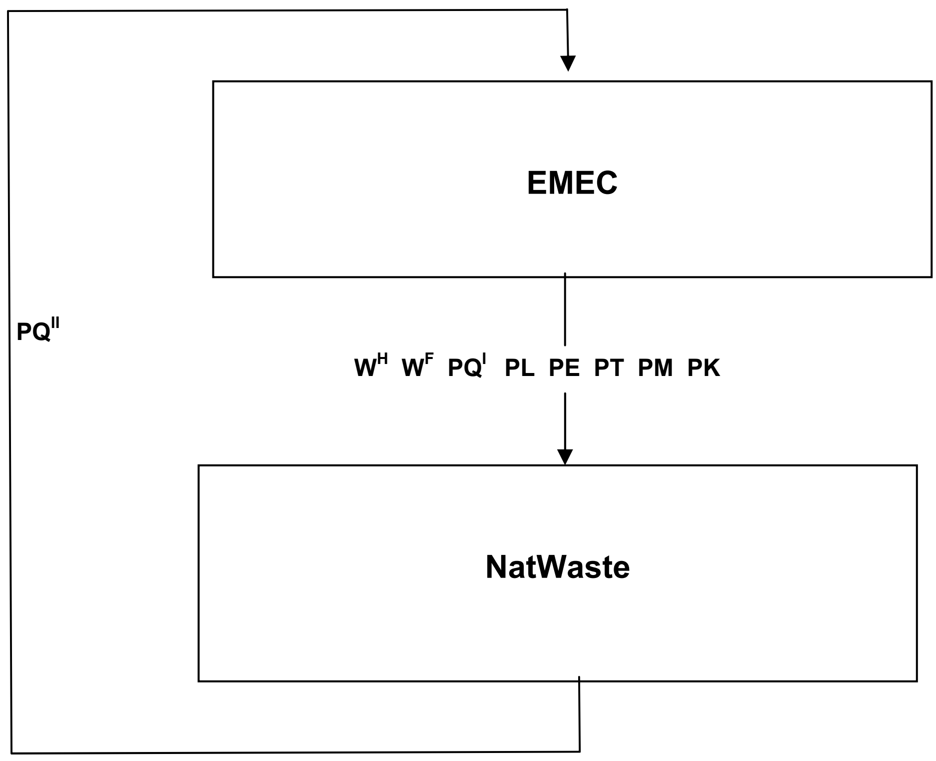
$$PQ_k^{II} \cdot \left(Q_k^{II} - \sum_j W_{j,k}^F - W_k^H \right) = 0 \qquad 10$$

To counteract a resource drain from the economy, we introduce a lump sum income transfer to households, TR^W, corresponding to the expenditures on waste disposal services by firms and households.

$$TR^W = \sum_k PQ_k^{II} \cdot \left(\sum_j W_{j,k}^F + W_k^H \right) \qquad 11$$

The prices *PK, PL, PE, PM* and *PT* of inputs used and recovered material and energy carriers supplied by the waste management system are exogenous to the system given by the equilibrium solution of the CGE-model.

Figure 3 The soft link between EMEC and NatWaste



3. Benchmark data and scenario assumptions

Data on waste generation are from the waste generation survey for 2006 reported by the Swedish EPA (2008). The data set was processed to fit into the framework of the economic model EMEC. The main difference in this adjusted data set is that products priced on a market, and therefore already accounted for as a common good in the economic data, are not treated as waste products, although classified as wastes according to the European Waste Catalogue (EWC) code. Sundqvist et al (2009) give a more thorough presentation of the processing of waste data.

The scenarios were developed within the research programme 'Towards Sustainable Waste Management' by an iterative process with programme participants representing a wide range of disciplines and the programme reference group which includes e.g. national authorities, stakeholders representing waste management and several industrial sectors and other Non-Governmental Organizations. The scenarios differ in assumptions about the development of a number of variables characterising the scenarios, as indicated by their names. Dreborg and Tyskeng (2008) present the assumed scenarios regarding future waste generation in further detail. The waste intensities[15] of 2006 are assumed to develop as given by the figures in Table 1 for yearly percentage changes between 2006 and 2030 according to Sundqvist et al (2009).

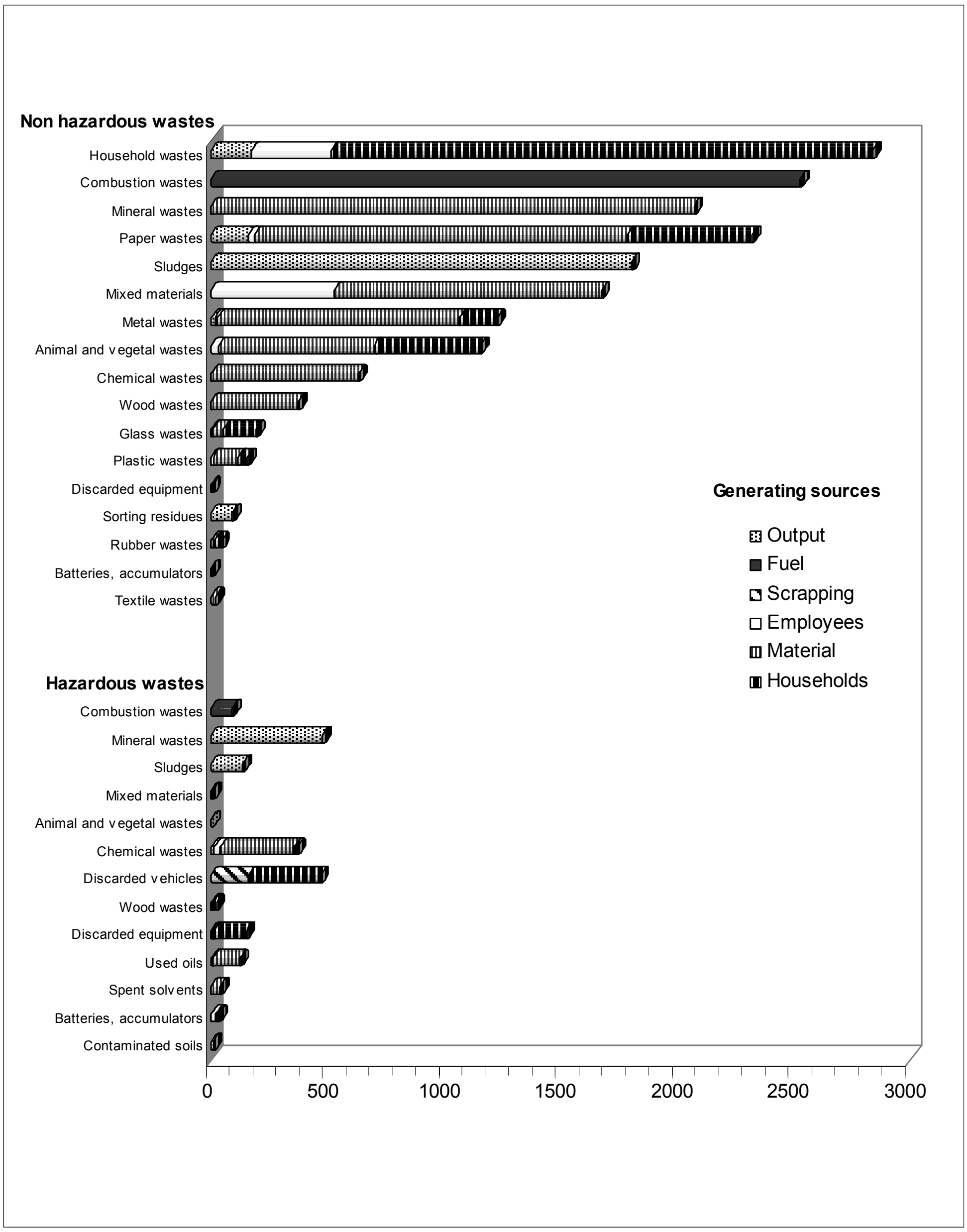
Benchmark data

In the benchmark data, the generation of non hazardous waste (17 185 Ktonnes) was almost nine times the generation of hazardous waste (1 950 Ktonnes) in 2006. Wastes generated by various industry sub sectors were attributed to five different sources of waste generation (material inputs, output, fuel combustion, employees and scrapping of capital) according to Sundqvist et al (2009). As shown in Figure 4, the most of non hazardous wastes are generated through firms' use of materials for input in production. Here, we identify 'Mineral waste', 'Paper waste', 'Mixed materials' and 'Metal wastes'. The wastes generated by fuel combustion and output also take large portions of non hazardous wastes: 'Combustion wastes' and 'Sludges'. The dominating types of hazardous waste are 'Mineral waste', 'Chemical waste' and 'Discarded vehicles'. The firms' activities (output) account for all generation of 'Mineral waste', whereas material inputs account for most of the generated 'Chemical waste'. Households' generation of non hazardous waste is dominated by 'Household waste', whereas their generation of hazardous waste consists of 'Discarded vehicles' and 'Discarded equipment'. All the benchmark data on economic variables are from the Swedish National Accounts published by Statistics Sweden.

[15] The waste intensities are measured in terms of kilograms of waste per SEK produced or spent on different goods, or in terms of kilograms of waste per person-hour used in the economic sectors.

Figure 4. Non-hazardous and hazardous wastes distributed among generating sources

Quantities of waste in Ktonnes, 2006.



Source: Sundqvist et al. (2009).

Scenarios

The key assumptions of economic variables affecting waste generation are presented for the scenarios in Table 1. The Reference scenario relates closely to that of the Long-Term Survey of the Swedish economy 2008.[16] World markets, assumingly, continue to develop as during the recent decades in the scenario 'Global sustainability, as well as in the Reference scenario. Climate change and sustainability policies, however, have a higher priority in the scenario 'Global sustainability', and the CO_2 permit price

[16] SOU 2008:105, Långtidsutredningen 2008 (The Long-Term Survey 2008).

is therefore assumed higher than in the Reference scenario. In addition, a more rapid technical change in the direction of saving primary resources brings about decreases in the waste intensities. The assumptions about structural changes do not differ between the scenarios but follow those made for Reference scenario.

Table 1. The economic key assumptions in the Reference and alternative scenarios.

Yearly percentage changes, 2006-2030 (Total percentage changes over the period are presented in Appendix D).

	Reference	Global sustainability	Global markets	Regional markets	European sustainability
GDP	2.2	2.2	3.3	1.8	1.8
World trade	4.4	4.4	4.8	3.8	3.8
Primary product prices	0.1	0.1	1.7	1.3	0.1
Oil prices	0.8	0.8	3.0	0.8	0.8
Employment	0.2	0.2	0.5	0.2	0.3
CO_2 Permit price €/tonne	39	78	29	39	59
Waste intensities[1]					
Firms' input-related	-1	-3	-3	-1	-1.5
Firms' Scrapping-related	-0.5	-1	-1	0	0
Firms' employees-related	0	-1	1	1	-1
Household waste	0	-2	1	1	-2.5

[1] Firms' waste intensities are assumed to relate to technological change except for employees-related waste intensities, which like households' waste intensities are assumed to relate to a changed behaviour. The waste intensities relating to firms' output and fuel combustion are assumed not to be altered by technological change 2006-2030.

Sources: The long term survey 2008 (SOU 2008:105, Bilaga 1), Dreborg and Tyskeng (2008) and Sundqvist et al (2009)

The scenario 'Global markets' is characterized by growing global markets and free trade but less concern for climate change and sustainability policies and thus the CO_2 permit price is assumed to be lower than in the Reference scenario. Expanding world trade leads to higher rates of employment and economic growth in Sweden but also to higher international prices of raw materials and fossil fuels. Here also, technical change goes in the direction of saving primary resources because of the increase in primary product prices and input-related waste intensities therefore decrease.[17] Less concern for sustainability policies, however, affect households' behaviour in the direction of increased waste intensities.

The globalisation trend weakens in the scenarios 'Regional markets' and 'European sustainability', where an increased protectionism among world regions holds world trade back and thereby also slows the rate of economic growth in Sweden down. Technical change is assumed less rapid in these scenarios than in the other scenarios due to the weaker globalisation trend. Climate change and sustainability policies are emphasised more in the scenario 'European sustainability' than in the scenario 'Regional markets'. In the scenario 'European sustainability', therefore, the CO_2 permit price is assumed higher and waste intensities are reduced. The different assumptions about the CO_2 permit price, however, have small effects on waste generation.

The waste intensities of 2006 calculated for the different waste sources are assumed to develop as given by the figures in Table 1 for yearly percentage changes between 2006 and 2030. Households' waste intensities are assumed to change by 1 to -2.5 per cent annually for the different scenarios. To capture several aspects such as

[17] Technical change also affects labour productivities in the scenarios as can be concluded by relating the growth rates to the employment rates shown in Table 2. It is seen that labour productivity growth at its highest yearly percentage rate in the scenario 'Global markets' (2.8) and at its lowest yearly percentage rate in the scenario 'European sustainability' (1.5)

technology development, real price change, and environmental awareness, the waste intensities are assumed to differ in accordance with the scenario assumptions regarding these aspects. The corresponding change in waste intensity of firms' input-related waste generation, are assumed to vary from -1 to -3 per cent annually, which reflects different levels of technological development and different developments of real prices.

A business as usual assumption of -1 per cent for input-related waste intensities in the Reference scenario could also be justified when examining data for waste generation in Swedish manufacturing 1993-2006. [18] The household-related waste intensity is assumed to be unchanged in the 'Reference scenario' on the basis that both household waste and private consumption increased by 2.7 per cent yearly from 1995 to 2007.[19]

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[18] By using data reported by the Swedish EPA (2007), (2008) and Statistics Sweden (2001), a yearly increase of 4 per cent the could be calculated for the waste generated in Swedish manufacturing 1993-2006. For the same period, the Swedish National Accounts report (see Statistical Report NR 10 SM 0801) a yearly 5 per cent increase in the intermediate consumption of Swedish manufacturing(in constant prices).

[19] Data on household waste is obtained from Swedish Waste Management (http://www.avfallsverige.se) and data on private consumption from Statistics Sweden (http://www.scb.se)

4. Future waste quantities and disposal prices

The future quantities of waste are closely coupled to economic growth given unchanged waste intensities in economic and human activities. However, economic growth might be unequally distributed between waste-intensive production and non-waste-intensive production. Thus, not only the magnitude but also the direction of economic growth will affect future waste generation. This effect on waste generation, however, will not differ among scenarios as the assumptions made here about the direction of economic growth coincide with the structural changes of the 'Reference scenario' for all the scenarios. The choice between preventing and generating different types of waste is affected by the prices of waste disposal services.

For future waste generation to decouple from economic growth its direction must change in favour of less waste intensive products and/or the waste intensities in economic and human activities must decrease. The waste intensities in economic activities decrease when the technological change develops in the direction of saving on those material inputs, which generate waste and when using production processes, which generate less waste or when installing capital equipment generating less waste. These effects on waste generation are best represented in the scenarios 'Global sustainability' and 'European sustainability'. The waste intensity of human activities decreases due to the changed household behaviour as modelled in the sustainability scenarios.

Future waste quantities

NON HAZARDOUS WASTES

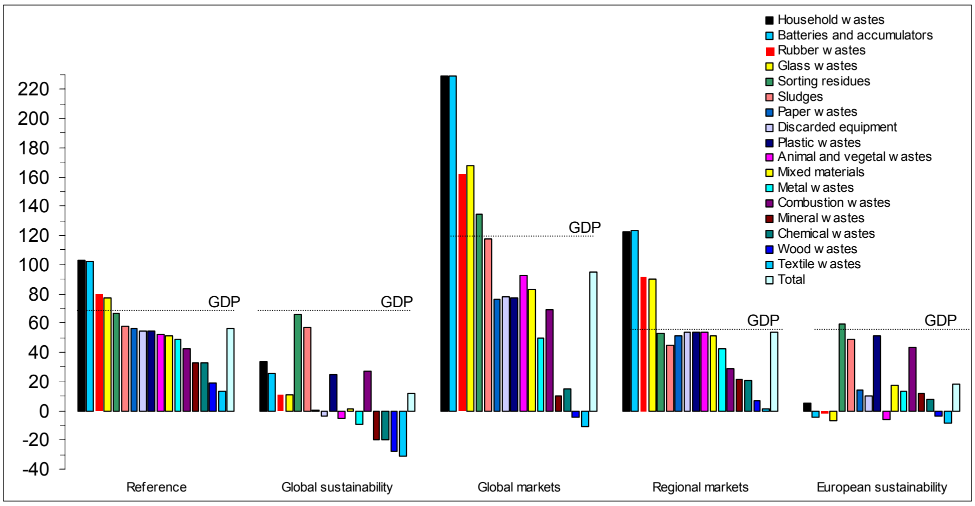
The waste bars depicted for alternative scenarios in Figure 5 reveal characteristic patterns in the generation of non hazardous wastes. The impact of economic growth on the waste generation is clear when comparing the waste bars of the scenario 'Global markets' with those of other scenarios. This scenario, with a yearly rate of economic growth being at least 1½ times that of any other scenarios, results in bars exceeding those of other scenarios when it comes to both total waste and most of the different types of waste. Technological changes resulting in less waste-intensive production processes and behavioural changes making household activities less waste intensive, as assumed in the scenarios 'Global sustainability' and 'European sustainability', obviously have a strong waste-reducing effect as can be concluded by comparing the waste bars of these two scenarios with those of other scenarios.

Total non hazardous waste increases the most in the scenario 'Global markets', (by 93 per cent until 2030), which has high economic growth. Total non hazardous waste will increase least for the scenario 'Global sustainability' (by 10 per cent until 2030), which has the same economic growth as the Reference scenario but the most rapid assumed decrease in waste intensities. The types of wastes affected the most by economic growth are Household wastes, Batteries and accumulators, Rubber wastes and Glass wastes, whereas Textile wastes, Wood wastes, Mineral wastes, Chemical wastes and Metal wastes are the waste types affected the most by reduced waste intensities of firms' production and households' activities.

Non hazardous waste grows at a lower rate in the scenario 'Global sustainability' than in the scenario 'European sustainability'. This observation indicates, that the generation of hazardous waste is more affected by decreasing waste intensities than by economic growth, as waste intensities decline more but economic growth is higher in the scenario 'Global sustainability' than in the scenario 'European sustainability'.

Figure 5. Generation of non hazardous wastes compared to GDP in alternative scenarios.

Percentage changes 2006-2030



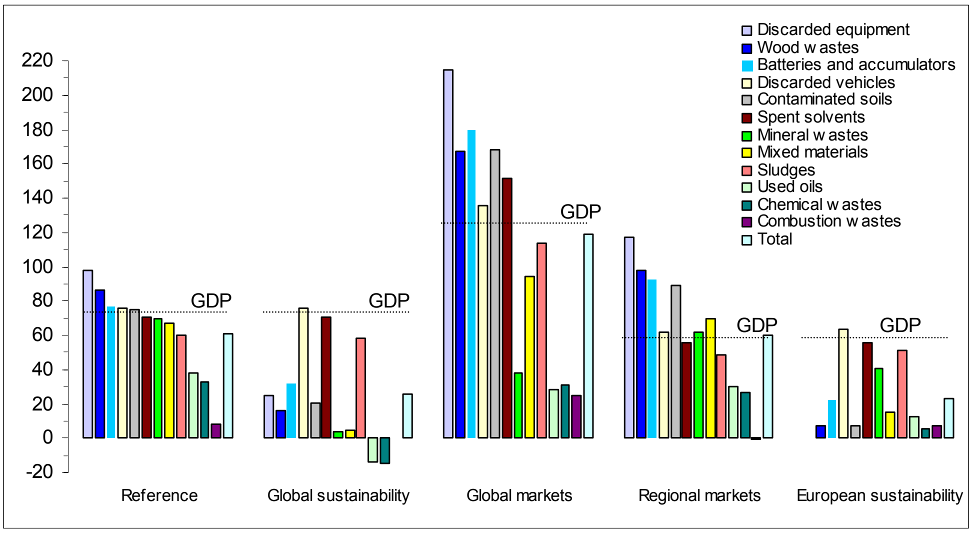
HAZARDOUS WASTES

The development of hazardous wastes is illustrated in Figure 6 by waste bars for the various scenarios. Total hazardous wastes grow by 116 per cent in the scenario 'Global markets' and this is far more than the waste growth in any other scenario. This scenario has also an economic growth, which is significantly higher than for other scenarios. The opposite of this waste growth is a growth of 21 per cent for hazardous wastes in the scenario 'European sustainability', with a low economic growth. For this scenario, we also assume the waste intensities of household activities to decrease more rapidly than for the scenario 'Global markets'.

Although, the overall reduction in the waste intensities of firms and households is significantly greater in the scenario 'Global sustainability' than in the scenario 'European sustainability', the rate of growth for total hazardous wastes is lower in the latter scenario. This is explained by a lower economic growth in the scenario 'European sustainability'. In this case, then, the impact of economic growth dominates over the impact of reducing intensities of hazardous wastes. This hypothesis is also underpinned by the observation that only four types of hazardous waste (Used oils, Chemical wastes, Mixed materials and Combustion wastes), show lower waste bars in the scenario 'Global sustainability' than in the scenario 'European sustainability'.

For hazardous waste, the rate of growth is lower in the scenario 'European sustainability' than in the scenario 'Global sustainability'. This observation indicates, that the generation of hazardous waste is less affected by decreasing waste intensities than by economic growth, as waste intensities decline more in the scenario 'Global sustainability' than in the scenario 'European sustainability', which has a lower economic growth.

Figure 6. Generation of hazardous wastes compared to GDP in alternative scenarios.
Percentage changes, 2006-2030



THE COUPLING BETWEEN ECONOMIC GROWTH AND WASTE GENERATION

The development of waste intensities in the economy can be illustrated by relating the growth in various types of waste to economic growth (GDP) as shown in Figure 5. By visualizing the impact of economic growth on waste generation in this way, the influence of assumed waste savings due to technological change or a changed household behaviour could be compared better among the different scenarios. In sum, the results show a relative decoupling between economic growth and *total* waste generation for all scenarios, but in varying degrees. Only for a limited number of waste types, we observe a decoupling in absolute terms in some of the scenarios. However, we note some distinguishing features among the scenarios.

Total non-hazardous waste will grow less than GDP from 2006 to 2030 in all scenarios (by -1, -12, -23, -37 and -58 per cent for the scenario 'Regional markets', Reference scenario, the scenario 'Global markets', the scenario 'European sustainability' and the scenario 'Global sustainability', respectively). The scenario 'Regional markets' has the least favourable assumptions about the waste intensities in firms' and households' activities. Therefore, this scenario shows the highest waste intensities for firms' and households' activities. Although, the economy's intensity of total hazardous waste decreases somewhat less than that of total non hazardous waste in all the scenarios, they share the same pattern of differences among scenarios.

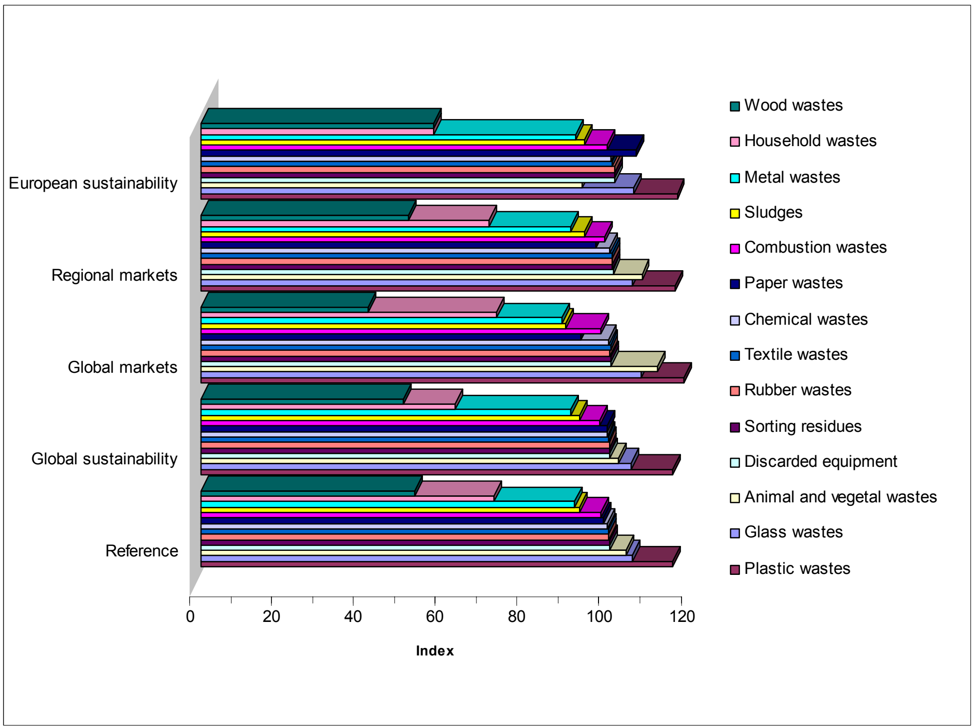
In the scenarios 'Global sustainability' and 'European sustainability', almost every type of non hazardous and hazardous waste will grow less than GDP. The development is most pronounced in the scenario 'Global sustainability', which has the lowest waste intensities for firms' activities, whereas waste intensities for households' activities are lowest in the scenario 'European sustainability'. Significant higher growth rates compared to that of GDP are noted for a few number of non-hazardous (Batteries and accumulators, Household wastes, Rubber wastes, Glass wastes and Sorting residues), as well as for some hazardous (Discarded equipment, Wood wastes, Batteries and accumulators, Discarded vehicles, Contaminated soils and Spent solvents) waste types in the scenario 'Global markets'. This scenario has the highest economic growth, decreasing waste intensities in firms' activities but increasing waste intensities in households' activities. In the scenario 'Regional markets', which has a low rate of economic growth and the highest waste intensities in firms' and households' activities, only seven non-hazardous and five hazardous waste types grow at significantly lower rates than GDP.

Future price development of waste disposal services[20]

The future development for prices of various waste disposal services sold to firms and households by the waste management sector will differ among waste types. For most of the waste disposal services, the real prices will be unchanged or will change little between 2006 and 2030, while for others, the real prices will decrease or increase as shown in Figure 7 for all the scenarios. The same pattern of price developments is identified, with diverging price developments for a few waste types, in all the scenarios. This is explained, mainly, by the fact that the future development for real prices of inputs, used in the waste treating processes, will differ only to a small extent among the scenarios. Three types of disposal services become dearer in all scenarios: 'Plastic wastes', 'Glass wastes' and 'Paper wastes'. Significantly decreasing prices of disposal services are observed for 'Wood wastes' and 'Household wastes', whereas e.g. 'Metal wastes', 'Sludges' and 'Animal and vegetal wastes' are noted for moderate price decreases in all scenarios. For most waste types, the future prices of disposal services will be unchanged or nearly unchanged in all scenarios.

Figure 7. Real prices of waste disposal services 2030.

Indices 2006=100



Transport intensive treatment processes such as waste collection dominate the net treatment costs for the types of wastes noted for increasing prices of disposal services.

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[20] As already discussed in the introduction, the prices of waste disposal services examined here are for non hazardous wastes as treatment processes could not be modelled for hazardous waste mainly due to lack of data.

As the real price of transports increases in all scenarios for the period 2006-2030, the treatment costs for disposal services using transports relatively intensive in the waste treatment processes will increase during the same period and thus also the prices of disposal services for 'Plastic wastes', 'Glass wastes' and 'Paper wastes'. For most of the waste types with decreasing prices of disposal services, the net treatment cost of processes are dominated by revenues from energy or material recovery. The real price of energy increases during the period 2006-2030 in all scenarios and this reduces the treatment costs for 'Wood wastes' used as a bio fuel and for 'Household wastes', which to a substantial part is treated by waste incineration with energy recovery.[21] Correspondingly, revenues from biogas production reduce the treatment costs for 'Sludges' and 'Animal and vegetal wastes', which to a substantial part are used for biogas production through anaerobic digestion. For 'Mineral wastes' and 'Metal wastes', the treatment costs are reduced by revenues from material recovery.

Firms and households react on increases in the prices of waste disposal services by reducing waste generation. The degree of waste reduction for a given price increase of course depends on the costs of firms and households to reduce waste generation. The waste reduction cost for firms is given by the cost of substituting waste generating for less waste generating inputs in production. Substitution could take place between the inputs of material, energy, labour and capital. In addition, waste intensive production could decline in favour of less waste intensive production. Households' experience a waste reduction cost when substituting waste intensive goods and services for less waste intensive but more expensive goods and services.

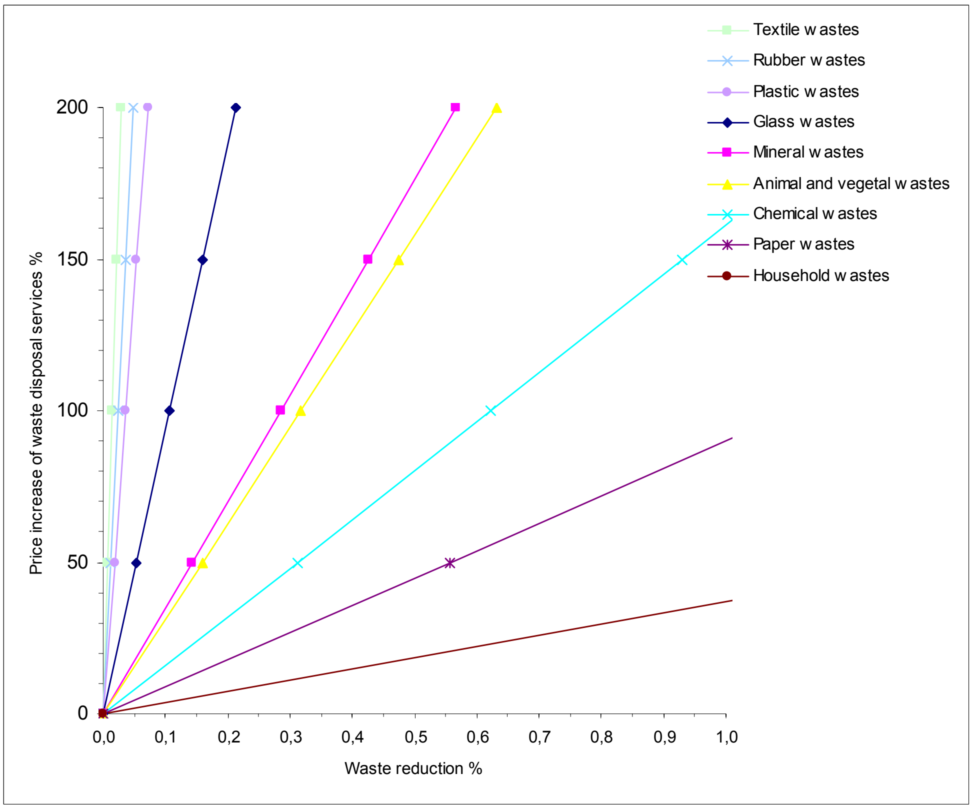
The reduction cost differs between wastes types as some types might be reduced at a lower cost than might others. The costs of waste reduction are shown in Figure 8 for various types of non-hazardous wastes.[22] The higher the reduction cost is, the more must the waste disposal price increase to result a given reduction in waste generation. The overall impression from the figure is that costs are high for reducing waste generation irrespective of the type of waste reduced, i.e. the waste treatment costs are low compared to the firms' and households' costs for reducing waste. It is least expensive to reduce 'Household wastes', which is reduced by 1 per cent for an increase of 30 per cent in the price of waste disposal services, and most expensive to reduce 'Textile wastes', which is reduced by less than 0.1 per cent for an increase of 200 per cent in the price of waste disposal services.

[21] 'Household wastes' is a complex waste type composed by a larger number of waste fractions (21 and 10 respectively, see Appendix C) which are treated by different waste treatment processes depending on their properties.

[22] Note that price increases are in relation to the waste disposal prices in 2030 for the Reference scenario.

Figure 8. Marginal reduction costs for non hazardous wastes.

Prices increases in relation to prices in 2030 for the Reference scenario.



This situation also means that taxes introduced in the waste management sector, in act to bring down the generation of waste, seem to have a very small effect of reducing any type of wastes. Households' waste generation is likely to be somewhat more affected by taxes than firms' waste generation since 'Household wastes', which is least expensive to reduce, is generated by mostly households. In production, waste is generated by incomplete absorption of materials in many cases. If the price increases of waste disposal services bring about the introduction of new waste preventing techniques, the waste reducing effects of taxes are underestimated with the model applied here as it accounts only for the waste reducing effects from substitution of production factors within the existing production techniques.

5. Concluding remarks and further research

The scope of future waste generation is here analysed with an integrated macroeconomic and waste management approach by using five potential scenarios of the Swedish economy 2006-2030: Reference, Global sustainability, Global markets, Regional markets and European sustainability. Waste generation is from a historical point of view closely related to economic growth and to illustrate this aspect, the economic scenarios differ in the growth rates of GDP. For a decoupling to take place between economic growth and waste generation, the waste generated by firms and households in relation to their economic activities must decrease in the future. This aspect is addressed by letting the waste intensities of firms and households differ among the scenarios. By establishing a soft link between a CGE-model (EMEC) and a systems engineering model for waste management (NatWaste) we consider the interaction between waste quantities and waste disposal prices or waste management costs when assessing future waste quantities.

The importance of economic growth as a driving force for generating non-hazardous wastes is apparent when comparing the waste growth from 2006 to 2030 in the five scenarios. The scenario 'Global markets', with a yearly rate of economic growth being at least 1½ times that in any of the other scenarios, demonstrates growth rates exceeding those of the other scenarios for total waste as well as for every waste type. On the contrary, technological changes resulting in less waste intensive production processes and behavioural changes making household activities less waste intensive have a strong reducing effect on the generation of non hazardous wastes. This is what takes place in the scenario 'Global sustainability', as revealed by its low waste growth compared to the scenarios 'Regional markets' and 'European sustainability', both demonstrating lower yearly rates of economic growth.

Future waste generation will be closely related to economic growth, according to the present analysis of five potential scenarios differing in GDP-growth rates 2006-2030. Waste quantities generated in the scenario 'Global markets', which has the highest GDP-growth rates, supersedes the waste quantities generated in the other scenarios, but the yearly decrease assumed for the firms' input-related waste intensities is enough to offset the impact of economic growth, i.e. to note a relative decoupling, of waste generation from economic growth. The impact of economic growth on waste generation is further illustrated by the scenario 'Global sustainability', which exhibits the same yearly decreases in firms' input-related waste intensities but a significantly lower yearly GDP growth rate than in the scenario 'Global markets'. For the scenario 'Global sustainability', we note a relative decoupling about twice that noted for the scenario 'Global markets'. A relative decoupling of waste generation takes place in all scenarios i.e. total waste quantities increase at a lower rate than GDP. Absolute decoupling, which entails total waste quantities to stabilize or reduce, does not take place in any of the scenarios. This means that the present Swedish Environmental quality objective of stabilizing waste quantities is not met in any of the scenarios with waste generation levels of 110 per cent up to nearly 200 per cent of that in 2006.

The real prices of various waste disposal services sold to firms and households by the waste management sector differ among waste types. The pattern of these differences is almost identical for most waste types in all the scenarios. This is explained mainly by the fact that the real prices of inputs used in the waste treating processes will not develop very differently among the scenarios. For most of the waste disposal services, the real prices will be practically unchanged between 2006 and 2030, while increasing or decreasing real prices are noted for some of the disposal services. The disposal services noted for increasing prices have transport intensive treatment processes, whereas the treatment processes of those noted for decreasing prices are receiving revenues from energy or material recovery.

Firms and households react on increases in the prices of waste disposal services by reducing waste generation. The higher the reduction cost is, the more must the waste disposal price increase to result in a given reduction in waste generation. The overall impression from our analysis is that costs are high for reducing waste generation irrespective of the type of waste reduced. In other words, the waste treatment costs are low compared to the costs for reducing waste. This situation also means that the use of policy instruments directed towards the waste management sector, and which increase the price of waste disposal services, will have very small reducing effects on the generation of all types of waste. To reduce waste generation of firms, the policy instruments introduced must bring about an introduction of waste preventing production techniques. Also according to our findings, it seems that policy instruments must affect households in the direction of less waste intensive behaviour more strongly than what we can expect to follow from pure price substitution in order to give a subsistent contribution to the decoupling of waste generation from economic growth. For example, the policy instruments used must affect the pattern of household consumption such as a differentiation of the value added tax (VAT) in favour of goods and services, which reduce the waste intensity of household consumption in accordance with some preliminary results reported by Forsfält (2009). It seems evident that waste prevention policies should primarily focus on the production and consumption activities generating wastes rather than on management of the wastes generated. Policy instruments introduced in the waste management sector are more likely to affect the choice of waste management solutions than prevent waste generation.

By linking a macroeconomic and a systems engineering model for waste management we consider, not only the interaction between waste quantities and waste management costs when assessing future waste quantities. We will also be able to capture the macroeconomic effects, such as GDP growth and structural changes, when designing policy instruments intended to prevent waste generation or direct waste management in a more sustainable direction. The approach allows us to analyse policy instruments introduced on a macroeconomic level (such as taxes on virgin materials and lower VAT on less waste intensive products) as well as instruments specifically directed towards the waste management sector (such as environmentally differentiated waste collections fees and ban on incineration of recyclable materials). By use of the linked models presented here, a number of such potential policy instruments will be assessed in the ongoing research program Towards Sustainable waste Management about sustainable future waste management in Sweden.

Appendix A

Table A1. Total wastes in 2006 and in economic scenarios for 2030. Ktonnes.

EWC-Stat code	Waste label	2006	Reference	Global sustain-ability	Global markets	Regional markets	European sustain-ability
Non hazardous wastes							
1.2, 1.4, 2, 3.1	Chemical wastes	633	841	508	699	771	709
3.2, 11, 11.3	Sludges	1 807	2 856	2 843	3 936	2 625	2 698
6	Metal wastes	1 232	1 833	1 122	1 846	1 759	1 400
7.1	Glass wastes	195	346	216	522	372	181
7.2	Paper wastes	2 328	3 633	2 331	4 108	3 531	2 661
7.3	Rubber wastes	44	79	49	115	84	43
7.4	Plastic wastes	159	246	154	283	245	174
7.5	Wood wastes	377	448	273	359	403	364
7.6	Textile wastes	20	23	14	18	20	18
8	Discarded equipment	6	9	7	11	9	9
8.1	Discarded vehicles	0	0	0	0	0	0
8.41	Batteries and accumulators	1	2	1	3	2	1
9	Animal and vegetal wastes	1 158	1 763	1 095	2 226	1 783	1 091
10.1	Household wastes	2 844	5 767	3 790	9 367	6 328	3 002
10.2	Mixed materials	1 678	2 534	1 703	3 072	2 539	1 976
10.3	Sorting residues	93	155	154	218	142	148
12	Mineral wastes	2 077	2 757	1 671	2 389	2 504	2 237
12.4	Combustion wastes	2 533	3 608	3 220	4 282	3 265	3 619
	Total	17 185	26 900	19 151	33 454	26 382	20 331
Hazardous wastes							
1.1	Spent solvents	40	68	41	55	65	56
1.3	Used oils	125	172	108	160	162	140
1.2, 1.4, 2, 3.1	Chemical wastes	372	493	317	486	470	394
3.2	Sludges	135	216	214	288	200	204
6	Metal wastes	0	0	0	0	0	0
7.1	Glass wastes	0	0	0	0	0	0
7.5	Wood wastes	24	45	28	64	47	26
7.7	PCB wastes	0	0	0	0	0	0
8	Discarded equipment	153	303	192	482	332	154
8.1	Discarded vehicles	471	824	567	1 262	892	503
8.41	Batteries and accumulators	36	64	47	101	69	44
10.2	Mixed materials	10	17	10	19	17	12
10.3	Sorting residues	0	0	0	0	0	0
12	Mineral wastes	481	822	819	1 208	747	748
12.4	Combustion wastes	92	100	92	115	91	99
12.6	Contaminated soils	11	19	19	26	18	18
	Total	1 950	3 143	2 454	4 266	3 110	2 398

Source: Sundqvist et al (2009) and calculations with the models EMEC and NatWaste.

Table A2. Total wastes generated by the industry sector in 2006 and in economic scenarios for 2030. Ktonnes.

EWC-Stat code	Waste label	2006	Reference	Global sustainability	Global markets	Regional markets	European sustainability
Non hazardous wastes							
1.2, 1.4, 2, 3.1	Chemical wastes	632	839	507	696	769	708
3.2, 11, 11.3	Sludges	1 807	2 856	2 843	3 936	2 625	2 698
6	Metal wastes	1 067	1 491	910	1 290	1 382	1 239
7.1	Glass wastes	53	53	34	49	49	43
7.2	Paper wastes	1 791	2 523	1 643	2 319	2 310	2 138
7.3	Rubber wastes	13	17	10	13	15	14
7.4	Plastic wastes	120	165	104	153	156	136
7.5	Wood wastes	377	448	273	359	403	364
7.6	Textile wastes	20	23	14	18	20	18
8	Discarded equipment	6	9	7	11	9	9
8.1	Discarded vehicles	0	0	0	0	0	0
8.41	Batteries and accumulators	0	0	0	0	0	0
9	Animal and vegetal wastes	702	802	499	689	729	639
10.1	Household wastes	517	902	774	1 480	973	704
10.2	Mixed materials	1 678	2 534	1 703	3 072	2 539	1 976
10.3	Sorting residues	93	155	154	218	142	148
12	Mineral wastes	2 077	2 757	1 671	2 389	2 504	2 237
12.4	Combustion wastes	2 533	3 608	3 220	4 282	3 265	3 619
	Total	13 486	19 182	14 366	20 974	17 890	16 690
Hazardous wastes							
1.1	Spent solvents	39	66	40	52	63	55
1.3	Used oils	122	166	104	151	156	137
1.2, 1.4, 2, 3.1	Chemical wastes	357	463	298	438	436	380
3.2	Sludges	135	216	214	288	200	204
6	Metal wastes	0	0	0	0	0	0
7.1	Glass wastes	0	0	0	0	0	0
7.5	Wood wastes	9	14	9	12	12	11
7.7	PCB wastes	0	0	0	0	0	0
8	Discarded equipment	14	22	18	24	21	21
8.1	Discarded vehicles	166	211	187	259	214	213
8.41	Batteries and accumulators	29	50	38	78	53	37
10.2	Mixed materials	7	11	6	9	10	9
10.3	Sorting residues	0	0	0	0	0	0
12	Mineral wastes	479	818	816	1 201	742	746
12.4	Combustion wastes	92	100	92	115	91	99
12.6	Contaminated soils	11	19	19	26	18	18
	Total	1 460	2 156	1 841	2 653	2 016	1 930

Source: Sundqvist et al (2009) and calculations with the models EMEC and NatWaste.

Table A3. Wastes generated by material input in the industry sector in 2006 and in economic scenarios for 2030. Ktonnes.

EWC-Stat code	Waste label	2006	Reference	Global sustain-ability	Global markets	Regional markets	European sustain-ability
Non hazardous wastes							
1.2, 1.4, 2, 3.1	Chemical wastes	632	839	507	696	768	708
3.2, 11, 11.3	Sludges	0	0	0	0	0	0
6	Metal wastes	1 041	1 462	882	1 247	1 352	1 212
7.1	Glass wastes	46	44	27	36	40	36
7.2	Paper wastes	1 601	2 206	1 335	1 865	2 009	1 859
7.3	Rubber wastes	13	17	10	13	16	14
7.4	Plastic wastes	109	148	90	123	136	123
7.5	Wood wastes	375	445	270	355	400	361
7.6	Textile wastes	20	23	14	18	20	18
8	Discarded equipment	2	3	2	2	3	2
8.1	Discarded vehicles	0	0	0	0	0	0
8.41	Batteries and accumulators	0	0	0	0	0	0
9	Animal and vegetal wastes	668	739	449	577	656	594
10.1	Household wastes	0	0	0	0	0	0
10.2	Mixed materials	1 147	1 623	985	1 410	1 480	1 317
10.3	Sorting residues	0	0	0	0	0	0
12	Mineral wastes	2 077	2 757	1 671	2 389	2 504	2 237
12.4	Combustion wastes	0	0	0	0	0	0
	Total	7 731	10 307	6 242	8 731	9 384	8 481
Hazardous wastes							
1.1	Spent solvents	39	66	40	52	63	55
1.3	Used oils	112	150	91	127	140	125
1.2, 1.4, 2, 3.1	Chemical wastes	317	391	236	320	359	323
3.2	Sludges	0	0	0	0	0	0
6	Metal wastes	0	0	0	0	0	0
7.1	Glass wastes	0	0	0	0	0	0
7.5	Wood wastes	8	12	7	9	11	9
7.7	PCB wastes	0	0	0	0	0	0
8	Discarded equipment	4	5	3	4	5	4
8.1	Discarded vehicles	0	0	0	0	0	0
8.41	Batteries and accumulators	7	9	6	8	8	7
10.2	Mixed materials	6	9	5	7	8	7
10.3	Sorting residues	0	0	0	0	0	0
12	Mineral wastes	0	0	0	0	0	0
12.4	Combustion wastes	0	0	0	0	0	0
12.6	Contaminated soils	0	0	0	0	0	0
	Total	493	642	388	527	594	530

Source: Sundqvist et al (2009) and calculations with the models EMEC and NatWaste.

Table A4. Wastes generated by the household sector in 2006 and in economic scenarios for 2030. Ktonnes.

EWC-Stat code	Waste label	2006	Reference	Global sustain-ability	Global markets	Regional markets	European sustain-ability
Non hazardous wastes							
1.2, 1.4, 2, 3.1	Chemical wastes	1	2	1	3	2	1
3.2, 11, 11.3	Sludges	0	0	0	0	0	0
6	Metal wastes	165	342	212	556	377	161
7.1	Glass wastes	142	293	182	473	323	138
7.2	Paper wastes	537	1 110	688	1 789	1221	523
7.3	Rubber wastes	31	62	39	102	69	29
7.4	Plastic wastes	39	81	50	130	89	38
7.5	Wood wastes	0	0	0	0	0	0
7.6	Textile wastes	0	0	0	0	0	0
8	Discarded equipment	0	0	0	0	0	0
8.1	Discarded vehicles	0	0	0	0	0	0
8.41	Batteries and accumulators	1	2	1	3	2	1
9	Animal and vegetal wastes	456	961	596	1 537	1 054	452
10.1	Household wastes	2 327	4 865	3 016	7 887	5 355	2 298
10.2	Mixed materials	0	0	0	0	0	0
10.3	Sorting residues	0	0	0	0	0	0
12	Mineral wastes	0	0	0	0	0	0
12.4	Combustion wastes	0	0	0	0	0	0
	Total	3 699	7 718	4 785	12 480	8 492	3 641
Hazardous wastes							
1.1	Spent solvents	1	2	1	3	2	1
1.3	Used oils	3	6	4	9	6	3
1.2, 1.4, 2, 3.1	Chemical wastes	15	30	19	48	34	14
3.2	Sludges	0	0	0	0	0	0
6	Metal wastes	0	0	0	0	0	0
7.1	Glass wastes	0	0	0	0	0	0
7.5	Wood wastes	15	31	19	52	35	15
7.7	PCB wastes	0	0	0	0	0	0
8	Discarded equipment	139	281	174	458	311	133
8.1	Discarded vehicles	305	613	380	1003	678	290
8.41	Batteries and accumulators	7	14	9	23	16	7
10.2	Mixed materials	3	6	4	10	7	3
10.3	Sorting residues	0	0	0	0	0	0
12	Mineral wastes	2	4	3	7	5	2
12.4	Combustion wastes	0	0	0	0	0	0
12.6	Contaminated soils	0	0	0	0	0	0
	Total	490	987	613	1613	1094	468

Source: Sundqvist et al (2009) and calculations with the models EMEC and NatWaste.

Appendix B

Classification of private production sectors

Production sector in EMEC	NACE Rev.1*	Sector label in the Swedish National Accounts
1. Agriculture	01	Agriculture and hunting
2. Fishery	05	Fishing
3. Forestry	02	Forestry and logging
4. Mining	13	Metal ore mining
	10-11,14	Other mining and quarrying
	37	Recycling
5. Other industries	15,16	Manufacture of food, beverage and tobacco
	17-19	Textile industries
	20	Manufacture of wood and wood products
6. Mineral products	26	Manufacture of non-metallic mineral products
7. Pulp and paper mills	21	Manufacture of pulp, paper and paper products
	22	Printing and publishing
8. Drug industries	244	Manufacture of pharmaceutical products
	245	Manufacture of soap and detergents
9. Other chemical industries	24 excl 244,245	Manufacture of chemicals and chemical products
	25	Manufacture of rubber and plastic products
10. Iron & steel industries	271-273	Iron steel basic industries
11. Non-iron metal industries	274-275	Non-ferrous metal basic industries
12. Engineering	28	Manufacture of metal products
	29	Manufacture of mechanical machinery
	30,31	Manufacture of electrical machinery and computers
	32	Manufacture of communication equipment
	33	Manufacture of measuring equipment, etc.
	34,35	Manufacture of transport equipment
	36,	Other manufacturing industries
13. Petroleum refineries	23	Petroleum refining
14. Electricity supply	401	Electricity
15. Hot water supply	403	Steam and hot water supply
16. Gas distribution	402	Gas manufacture and distribution
17. Water and sewage	41	Water supply and sewage disposal
18. Construction	45	Construction
19. Railroad transports	601	Railway road transports
20. Road goods transports	6024	Road goods transports
21. Road passenger transports	6021-6023	Road passenger transports
22. Sea transports	61	Water transports
23. Air transports	62	Air transports
24. Other transports	63	Other transport activities
	64	Communications
25. Services	50-52	Wholesale and retail trade
	55	Restaurants and hotels
	65	Financial institutions
	66	Insurance
	71-74	Business services
	75,80-85,90-95	Other private services
26. Real estate	70	Letting of dwellings and other real estate

*Nomenclature Général des Activités Economiques dans les Communautés Européennes. The statistical classification of economic activities in the European Community amended in March 1993.

Definition of commodities

Commodity in EMEC	CPA code*	Commodity label in the Swedish National Accounts
1. Agricultural products	01	Products of agriculture and hunting
2. Fish	05	Fish and fishing products
3. Timber	02	Products of forestry and logging
4. Bio fuels	02 pt	Wastes from logging
5. Metal ores	13	Metal ores
	11,14	Other mining and quarrying products
	37	Recycled products
6. Coal	10	Coal
7. Products n.e.c.	15,16	Food products, beverages and tobacco products
	17-19	Textiles and textile products
	20	Wood and wood products
8. Mineral products	26	Non-metallic mineral products
9. Pulp and paper	21	Pulp, paper and paper products
	22	Printed matter
10. Pharmacy products	244	Pharmaceuticals and medical chemicals
	245	Soap,detergents and cosmetics
11 Other chemical products	24 excl 244,245	Chemicals and chemical products
	25	Rubber and plastic products
12. Iron and steel	271-273	Basic iron and steel , tubes and wires
13. Other metals	274,275	Basic non-ferrous metals
14. Engineering products	28	Metal products
	29	Mechanical machines
	30,31	Electric machines and computers
	32	Communication equipment
	33	Measuring equipment
	34,35	Transport equipment
	36,37	Other manufactured products
15. Fuels	23200 pt	Heating oils
16. Motor fuels	23200 pt	Motor gasoline,diesel and jet fuels
17. Other petroleum products	23200 pt	Other refined petroleum products
18. Crude petroleum	11	Crude petroleum
19. Electricity	401	Electricity
20. Steam and hot water	403	Steam and hot water
21. Gas	402	Manufactured and distributed gas
22. Fresh water	41	Collected, purified and distributed water
23. Buildings	45	Construction works
24. Rail transports	601	Rail transports
25. Passenger transports	6021 pt,6023	Passenger transports by bus
	6022	Passenger transports by taxi
26. Large truck transports	6024 pt	Goods transports by trucks > 32 tonnes
27. Medium truck transports	6024 pt	Goods transports by trucks 3.5 - 32 tonnes
28. Small truck transports	6024 pt	Goods transports by trucks < 3.5 tonnes
29. Sea transports	61	Sea transports
30. Air transports	620	Air transports
31. Other transports	63	Other transport products
	64	Communication products
32. Services	50-52	Wholesale and retail trade products
	55	Restaurant and hotel services
	65	Financial services
	66	Insurance services
	71-74	Business services
	75,80-85,90-95	Other private services
33. Dwellings	70	Real estate services

- EU Classification of products by Activity (CPA).

Appendix C

Waste fractions modelled in EMEC and in NatWaste

EWC-Stat waste code	Waste fractions in EMEC	Waste fractions in NatWaste
Non hazardous waste		
1.2, 1.4, 2, 3.1	Chemical wastes	Chemical
3.2, 11, 11.3	Sludges	Industrial Sludge Organic Industrial Sludge Non-organic Sewage Sludge
6	Metal wastes	Aluminium Ferrous Stainless Other Metal
7.1	Glass wastes	Glass Clear Glass Colour
7.2	Paper wastes	Cardboard Corrugated Board Newsprint Office Paper Fibre Reject
7.3	Rubber wastes	Rubber
7.4	Plastic wastes	PE PP PET PS PVC PUR PC Agricultural Film Agricultural Cans Agricultural Other
7.5	Wood wastes	Wood
7.6	Textile wastes	Textile
8	Discarded equipment	Equipment
8.1	Discarded vehicles	*Not included*
8.41	Batteries and accumulators	*Not included*
9	Animal and vegetal wastes	Manure Animal waste Animal waste to be hygenised Vegetal waste Park waste Foods waste
10.1	Household wastes	Household and similar waste Foods Park Newsprint Corrugated Board Cardboard PE PS Glass Clear Glass Colour Metals Landfill Residues Hazardous waste Equipment Wood Textile Other Combustible waste Bulky waste Paper Plastics Wood Plaster Inert mix

Waste fractions modelled in EMEC and in NatWaste (continued)

EWC-Stat waste code	Waste fractions in EMEC	Waste fractions in NatWaste
Non hazardous waste (continued)		
10.2	Mixed materials	Combustible wastes Paper Plastics Wood Non-Combustible wastes Plaster Inert mix Mixed wastes Paper Plastics Wood Plaster Inert mix
10.3	Sorting residues	Recycled fibres reject Sorting ashes
12	Mineral wastes	Plaster Inertmix Asphalt
12.4	Combustion wastes	Steel Industry Slag, blast-furnace Steel Industry Slag, other Wood Flyash Other Ashes
Hazardous waste		
1.1	Spent solvents	*Not included*
1.3	Used oils	*Not included*
1.2, 1.4, 2, 3.1	Chemical wastes	*Not included*
3.2	Sludges	*Not included*
6	Metal wastes	*Not included*
7.1	Glass wastes	*Not included*
7.5	Wood wastes	*Not included*
7.7	PCB wastes	*Not included*
8	Discarded equipment	*Not included*
8.1	Discarded vehicles	*Not included*
8.41	Batteries and accumulators	*Not included*
10.2	Mixed materials	*Not included*
10.3	Sorting residues	*Not included*
12	Mineral wastes	*Not included*
12.4	Combustion wastes	*Not included*
12.6	Contaminated soils	*Not included*

Appendix D

The economic key assumptions in the Reference and alternative scenarios.

Total percentage changes over the period 2006-2030

	Refer-ence	Global sustainability	Global markets	Regional markets	European sustainability
GDP	69	69	118	53	53
World trade	181	181	208	145	145
Primary product prices	2	2	50	36	2
Oil prices	21	21	103	21	21
Employment	5	5	13	5	8
CO_2 Permit price €/tonne	39	78	29	39	59
Waste intensities coefficients[1]					
Firms' input-related	-21	-52	-52	-21	-30
Firms' scrapping-related	-11	-21	-21	0	0
Firms' employees-related	0	-21	27	27	-21
Household waste	0	-38	27	27	-46

[1]Firms' waste intensities are assumed to relate to technological change except for employees-related waste intensities, which like households' waste intensities are assumed to relate to a changed behaviour. The waste intensities relating to firms' output and fuel combustion are assumed not to be altered by technological change 2006-2030.

Sources: The long term survey 2008 (SOU 2008:105, Bilaga 1), Dreborg and Tyskeng (2008) and Sundqvist et al (2009)

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