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Decoupling waste generation from economic growth — A CGE analysis of the Swedish case

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ABSTRACT

Over the past decades, we have seen the quantities of solid waste increase in close relation to economic growth. To tackle this problem of continuing waste growth, the EU has on its agenda that waste generation should decouple from economic growth within the EU in the future. Sweden also has stated a target of non-increasing future waste quantities. The strength of the policy measures needed to attain this target is here illustrated by comparing the waste intensity outcomes in a 'Decoupling scenario' and a 'Baseline scenario' of the Swedish economy 2006–2030. A Computable General Equilibrium (CGE) model is used for linking waste generation to firms' material input, firms' production and households' consumption when projecting future quantities of hazardous and non-hazardous waste in Sweden. We show that to offset the effect of economic growth on waste generation in the 'Decoupling scenario', the intensities of material-related wastes must decrease at a yearly rate that is about twice the historically estimated reduction rate used in the 'Baseline scenario'. The reduction in the intensities of waste related to firms' production and households' consumption must also be substantial compared to historical estimates.

1. Introduction

The quantities of solid waste have grown steadily along with Gross Domestic Products (GDPs) over the past decades. For example, the total quantity of municipal waste per capita increased by 29% in North America, 35% in OECD, and 54% in the EU15 from 1980 to 2005. This development holds also for Sweden, where the per capita municipal waste quantity increased by 60% over the same period.[1] Moreover, waste generation in Swedish manufacturing industries increased by 66% from 1993 to 2006.[2] Although, a positive relationship seems to exist between economic growth and waste generation, its environmental costs might still have decreased in many countries because of waste management policies directed towards increased recycling activities.[3]

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 (in conformity with the literature, we refer to this situation, where the waste quantities still increase but less than in proportion to the increase of GDP, as a relative decoupling of waste generation from GDP). Yet, 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 within the EU (in a situation like this, where the waste quantities stabilize or decrease while GDP still increases, we will have an absolute decoupling of waste generation from GDP). The reductions of waste quantities necessary in the future to attain the objective have so far not been specified at the EU level. Hence, this objective is unlikely to be achieved within the next few decades. Some projections of future waste quantities for the EU do indicate relative decoupling of waste generation from GDP and household consumption (Mazzanti, 2008; Mazzanti and Zoboli, 2008; Skovgaard et al, 2005; and Skovgaard et al., 2007), while others, e.g. Mazzanti and Zoboli (2005) find no evidence for absolute or relative decoupling.

Parallel to the efforts of the EU, the Swedish parliament has enacted 16 environmental quality objectives serving as benchmarks for the national environmental policy, which ultimately seeks to solve the major environmental problems within one generation (i.e. before 2020). One of the 16 objectives concerns future waste quantities and an eventual absolute decoupling of waste generation from GDP. According to the objective, 'A good built environment': 'The total quantity of waste must not increase ….' However, according to the last evaluation performed by the Swedish Environmental Objectives

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

[2] This figure was calculated using the data reported by the Swedish EPA (2007), (2008) and Statistics Sweden (2001) on waste generated in Swedish manufacturing.

[3] For example, Berglund and Söderholm (1997) find a strong positive relationship between waste paper recovery rates and income for rich countries.

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Council (2008), it will be very difficult to attain the target of non-increasing waste quantities. The findings reported in the present paper strongly support this conclusion, especially if additional policy measures aimed to hinder future waste generation in Sweden are not introduced.

Attention has been given to the use of CGE models and econometric models during the last decade 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 trash with a CGE model of the Chinese economy. 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 Ibenholt (1997) to simulate future waste quantities in Sweden. They extend this approach, however, by linking the generation of several waste types to a number of production factors. Skovgaard et al. (2005) and Skovgaard et al. (2007) employ an econometric model that relates eight waste flows to population growth, economic activity and a time trend to estimate future waste quantities in the EU member states. Johnstone and Labonne (2004) estimate the correlations between waste quantities and income and between waste quantities and population density using panel data covering the period 1980–2000 for the 30 OECD members. Many of the previous studies have tended to focus on econometric analysis, while the present paper employs a CGE-model, thus adding a theoretically consistent description of the interdependence between economic sectors. Moreover, the present analysis adds to referred CGE studies by assessing the future policy challenge of decoupling waste generation and economic growth.

In the present paper, we illustrate the range of policy measures necessary to attain the Swedish objective of non-increasing future waste quantities by comparing the historical waste intensities used in the 'Baseline scenario' with those applied in the 'Decoupling scenario' to achieve absolute decoupling by 2030. The CGE model of the Swedish economy used by Sjöström and Östblom (2009) is here applied to project future quantities of various hazardous and non-hazardous waste types in the two scenarios. The 'Baseline scenario' complies with the official projection of the Swedish economy until 2030 (The Swedish Long Term Survey, 2008). It is also furnished with historical figures of the intensities of material-related, production-related and household-related non-hazardous and hazardous waste in economic and human activities. In the 'Decoupling scenario', these waste intensities are adjusted to produce an absolute decoupling of material-related, production-related, household-related and total wastes.

A presentation of the CGE model and the method for introducing waste intensities into the model follows in Section 2.1. The rest of Section 2 describes the benchmark data and the scenario assumptions. Section 3 reports the results and finally Section 4 presents some concluding remarks.

2. Method, Data and Scenario Assumptions

To capture the effects of economic growth on waste generation 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 and use of waste-generating inputs and outputs. In the present analysis, we apply a CGE model exhibiting such adjustment mechanisms when households and firms choose among a number of waste-generating and non waste-generating inputs and outputs. The benchmark year for the economic data and the data on waste generation is 2006 because of practical reasons. This year is the benchmark of the 'Long-Term Survey of the Swedish economy 2008', which is considered, here, when setting up our 'Baseline scenario', and is also the year of the latest waste generation survey reported by the Swedish EPA. In the 'Baseline scenario', waste intensities are assumed to develop in accordance with historical figures, whereas those in the Decoupling scenario', are adjusted to accomplish absolute decoupling.

2.1. Method

The Environmental Medium Term Economic Model (EMEC) applied here 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.[4] The model is implemented in GAMS (General Algebraic Modelling System, http://www.gams.com/default.htm). EMEC is a static CGE-model with 26 industries and 33 composite commodities.[5] Produced goods and services are exported and used together with imports to create composite commodities for domestic use. Besides utility maximizing households, subject to an income restriction, and profit maximizing firms, subject to resources restrictions, the model includes a public sector and a foreign sector. A single government agent, with tax incomes equal to households' income transfers and the exogenous public consumption, produces public goods and services. The small country assumption is adopted and the problem of overspecialization is handled by the Armington assumption.

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 and thus the model runs with exogenous interest rate. All factors can move freely between domestic sectors. Perfect competition and no economies of scale in production are assumed for all markets. Technical change is exogenous to the economy and the exogenous current account ratio (in relation to GDP) is used as closure rule. Östblom and Berg (2006) give a thorough presentation of the model.

The waste flows in the economy relate to production and consumption of commodities, and thus economic activity generates waste through input use in production and households' use of outputs. Production demands inputs of labour, capital, energy, materials and transports in the model. Firms are cost minimising in the choice of these inputs for producing outputs. Materials, labour, capital and energy but not transports are waste-generating inputs in the model. Substitution among waste-generating inputs, and productivity changes in the use of the inputs, affect firms' waste flows. Households' waste flows are affected by their consumption of goods and services. The firms' production function and the households'

[4] The EMEC model was evaluated through a number of climate policy analyses conducted in Sweden during the last ten years and the results were reported by Governmental committees as well as in peered journals. 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 CO_2 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).

[5] The sectors in EMEC are: agriculture, fishery, forestry, mining, other industries, mineral products, pulp and paper mills, drug industries, other chemical industries, iron and steel industries, non-iron metal industries, engineering, petroleum refineries, electricity supply, hot water supply, gas distrubution, waster and sewage, construction, railroad transports, road goods transports, road passenger transports, sea transports, air transports, other transports, services, and real estate.

demands, as well as the waste-generating procedures of firms and households, are presented in the following sections.[6]

Firms' production requires primary factors as well as inputs of materials, transports and energy.[7] Output Y is produced by means of labour L, capital K, energy carriers E, materials M and transports T. The demand for the production factors then becomes a function of the corresponding relative prices PK, PL, PE, PM and PT and factor productivity MP_g, which may differ among production factors, allowing for a biased technical change.

The production function for sector i is:

$$Y_i = f_i(K_i, L_i, E_i, M_i, T_i) \qquad i = 1, ..., n. \tag{1}$$

The demand for production factors K, L, E, M, T per unit of production is:

$$X_g = MP_g \, \psi_g(PK, PL, PE, PM, PT) \qquad g = K, L, E, M, T \,. \tag{2}$$

Waste is generated by incomplete absorption of material inputs (M) or by the resulting waste products in the production (Y) of goods and services. Waste can also be generated by fuel combustion (E), and disposal of scrapped capital equipment (K), and due to employees' garbage (L), whereas transports (T) are not, here, a waste-generating production factor. All waste intensities w, except that for employee-related waste are subject to technical change and are generally assumed not to increase over time t. Besides the changes in waste intensities, firms' waste generation is affected by factor substitution as the waste intensity differs among factors of production. Especially, the model EMEC exhibits a number of possibilities for substituting among energy carriers and for example, a substitution of electricity (used for indoor heating) for district heating will increase the generation of combustion wastes. [8] Thus:

$$w(t+1) \leq w(t) \qquad w \neq w^L \,.$$

Generation of waste $W_{i,k}$ type k by firm i at any point of time is:

$$W_{i,k} = \sum_g \left(w_{i,k}^g \cdot X^g \right) + w_{i,k}^y \cdot Y_i \qquad g = K, L, E, M \,. \tag{3}$$

Total generation of waste type k by firms is:

$$W_k = \sum_i W_{i,k} \qquad k = 1, ..., m. \tag{4}$$

The representative consumers maximise the utility of consumption. The households' demand for various goods and services HC, then, is a function of relative prices PHC and the total expenditures PKL.

Households' demand function:

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

Households generate waste by consuming goods and services. We assume the amount of all household garbage to be in proportion to the demand for housing services HC_5**.** This approach is similar to Johnstone and Labonne (2004), who assume that households derive utility from consumption of a composite good and household waste collection. In our case, waste collection is part of housing services. The wage intensities of households could increase or decrease over time because of changed behaviour.

The generation of waste type k by household H, W_k^H is:

$$W_k^H = w_{k,5} \cdot HC_5 \tag{6}$$

2.2. Benchmark Data

All economic data comes from the Swedish National Accounts. Data on waste generation are from the waste generation survey for 2006 reported by the Swedish EPA (2008) was processed to fit into the framework of the economic model EMEC. The main difference in this 'improved' 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, but are classified as wastes according to the European Waste Catalogue (EWC) code. In addition, wastes generated by various industry sub sectors are attributed to different sources of waste generation. Sundqvist and Stenmarck (2009) give a more thorough presentation of the processing of waste data.

As shown in Table 1, the amount of non-hazardous waste generated was about ten times that of hazardous waste in 2006.[9] Most of the non-hazardous and hazardous waste are generated through firms' production activities and use of materials for inputs in production. Of the non-hazardous waste generated primarily in this way, 'Animal and vegetal waste' is generated in the largest amounts, followed by 'Combustion waste', 'Paper waste', 'Sludges' and 'Mineral waste'. 'Combustion waste' and 'Sludges' are solely generated by firms' production activities, whereas 'Mineral waste' is generated through use of material inputs in production. The dominating types of hazardous waste originating from firms' production activities or material inputs are 'Mineral waste', 'Chemical waste' and 'Combustion waste'. Firms' production activities account for all generation of 'Mineral waste' and 'Chemical waste', whereas material inputs account for most of the generated 'Combustion waste'. In terms of non-hazardous waste, households primarily generate 'Household waste', whereas their hazardous waste consists primarily of 'Discarded vehicles' and 'Discarded equipment'.

Over time, technological development and changed household behaviour, due to e.g. environmental awareness, may change waste intensities in the economic activities of firms and households. In the 'Baseline scenario', we apply waste intensities observed over the past decade for economic activities of firms and households. For firms' material-related waste intensities, an annual decrease in the waste intensity of 1% could be justified when examining data for waste generation in Swedish manufacturing 1993–2006. [10] Firms' waste generation is also related to the production level, fuel combustion,

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[6] Firms' production functions and households' utility functions are specified as nested CES (Constant Elasticity of Substitution) functions in the model. The art of finding elasticity values for all the CES functions of a large CGE model like EMEC seldom includes an econometric estimation of the models equations due to the large amount of data needed and the huge effort of estimating all of the equations. The procedure adopted is instead that of picking the elasticity values by surveying econometric studies concentrating on the estimation of a few of all the relations captured by a CGE model. The elasticity values of substitution are generally "guesstimated" as concluded by Bergman (2005). The elasticity values collected from such partial studies might not interact very well within a general equilibrium framework, so there must always be some kind of judgement approach considering the accuracy of model results, when setting the elasticity values of a CGE model. All the elasticity values of the model and their sources are found in Östblom and Berg (2006).

[7] The representative firm is assumed to choose an optimal mix of skilled and unskilled 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 (including an optimal transport solution) in the creation of energy-material input. An optimal mix of value added and energy-material input is chosen at the highest level to produce the firm's output.

[8] The data on waste generation, however, allow only for relating combustion wastes to a fuel aggregate. The combustion wastes relate to the ashes of biofuel, which is dominating in the fuel aggregate used for district heating in Sweden.

[9] The classification of wastes into non-hazardous and hazardous wastes is regulated by the EWC code.

[10] By using data reported by the Swedish EPA (2007), (2008) and Statistics Sweden (2001), a yearly increase of 4% 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% increase in the intermediate consumption of Swedish manufacturing(in constant prices).

Table 1
Non-hazardous and hazardous wastes distributed among generating sources in 2006.

Waste label	Non-hazardous wastes				Hazardous wastes			
	Total Ktonnes	Production[a] %	Materials %	Household %	Total Ktonnes	Production[a] %	Materials %	Household %
Animal and vegetal wastes	4704	72	20	8	0	0	0	0
Combustion wastes	2533	100	0	0	260	100	0	0
Household wastes	2665	13	0	87	0	0	0	0
Mineral wastes	2083	0	100	0	481	100	0	0
Paper wastes	2328	8	69	23	0	0	0	0
Sludges	2099	100	0	0	135	100	0	0
Mixed materials	1689	32	68	0	10	10	60	30
Metal wastes	1232	2	84	13	0	0	0	0
Chemical wastes	633	0	100	0	372	11	85	4
Discarded vehicles	0	0	0	0	471	35	0	65
Wood wastes	377	1	99	0	24	4	33	63
Glass wastes	195	4	24	73	0	0	0	0
Plastic wastes	159	7	69	25	0	0	0	0
Discarded equipment	6	67	33	0	153	7	3	91
Used oils	0	0	0	0	125	8	90	2
Sorting residues	93	100	0	0	0	0	0	0
Rubber wastes	44	0	30	70	0	0	0	0
Spent solvents	0	0	0	0	40	0	98	3
Batteries and accumulators	1	0	0	100	36	61	19	19
Textile wastes	20	0	100	0	0	0	0	0
Contaminated soils	0	0	0	0	11	100	0	0
Total	20,861	44	38	17	2118	54	23	23

[a] Production includes wastes generated by output, fuel combustion, employees and scrapping of capital.

disposal of scrapped capital equipment and employees' garbage. Lack of relevant data restrains us from estimating changes in these waste intensities; we therefore assume them unchanged in the 'Baseline scenario'. In what follows, we refer to these as production-related waste. The household-related waste intensity is also assumed unchanged in the 'Baseline scenario'. This assumption is based on the fact that both household waste and private consumption increased by 2.7% yearly from 1995 to 2007.[11]

2.3. Scenario Assumptions

The present analysis compares the generation of waste in a 'Decoupling scenario' and in a 'Baseline scenario'. The Baseline scenario relates closely to that of the Long-Term Survey of the Swedish economy 2008.[12] The yearly percentage growth in the key economic variables GDP, private consumption, investments, exports and imports are 2.2, 3.1, 2.1, 4.0 and 4.5, respectively, for the period 2006–2030. Most notable in this projection of the key economic variables are the high growth rate of private consumption and the low growth rate of exports compared to corresponding figures for the recent decade. In the 'Baseline scenario', waste intensities are assumed to develop in accordance with historical figures, which means that material-related waste intensities decrease by 1% per year, while the intensities of production-related and household-related wastes are unchanged from 2006 to 2030. The 'Decoupling scenario' differs from the 'Baseline scenario' in that these waste intensities are adjusted to accomplish absolute decoupling between economic growth and the generation of non-hazardous wastes as well as the generation of hazardous wastes.

3. Comparison of the Scenario Results

The future amounts of waste are closely tied to economic growth given unchanged waste intensities in economic and human activities. For the 'Baseline scenario', the changes in waste intensities are based on the historical estimates reported in Section 3. We assume only the material-related waste intensities to decrease, whereas the intensities related to production and households are assumed to remain unchanged during the period. We observe relative but not absolute decoupling of waste quantities in the 'Baseline scenario'. This development does not comply with the Government's target of non-increasing waste quantities in the future, i.e. absolute decoupling of waste generation from economic growth. Therefore, to set up the 'Decoupling scenario', we decrease the waste intensities of the 'Baseline scenario' for the various types of non-hazardous and hazardous wastes in order to achieve absolute decoupling in the generation of wastes related to material, production and households, respectively. In this way, we will have an absolute decoupling also for total non-hazardous and total hazardous wastes.

3.1. Baseline Scenario

Fig. 1 shows the growth of non-hazardous wastes and hazardous wastes distributed among generating sources in the 'Baseline scenario'. As can be seen, we distribute the wastes among the generating sources firms' material input, firms' production (including output-related, employees-related, capital-related and fuel-related wastes) and household consumption.

The waste bars depicted for the 'Baseline scenario' in Fig. 1 reveal characteristic patterns in the generation of non-hazardous wastes. Total non-hazardous waste increases by 52% until 2030 and the waste types affected the most by economic growth are batteries and accumulators, Household wastes, rubber wastes and glass wastes, whereas the waste types affected the least are textile wastes, wood wastes, mineral wastes, chemical wastes and metal wastes. Growth in total non-hazardous wastes is almost uniformly distributed across the three waste-generating sources, whereas growth in the different non-hazardous waste types is found to be very unequally distributed across waste-generating sources. Households' waste generation is dominating among the waste types with the highest growth rates. Waste types with low growth rates are typically generated through firms' material input.

The development of hazardous wastes in the 'Baseline scenario', also illustrated in Fig. 1 by waste bars, differs somewhat from the

[11] 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).
[12] SOU 2008:105, Långtidsutredningen 2008 (The Long-Term Survey 2008).

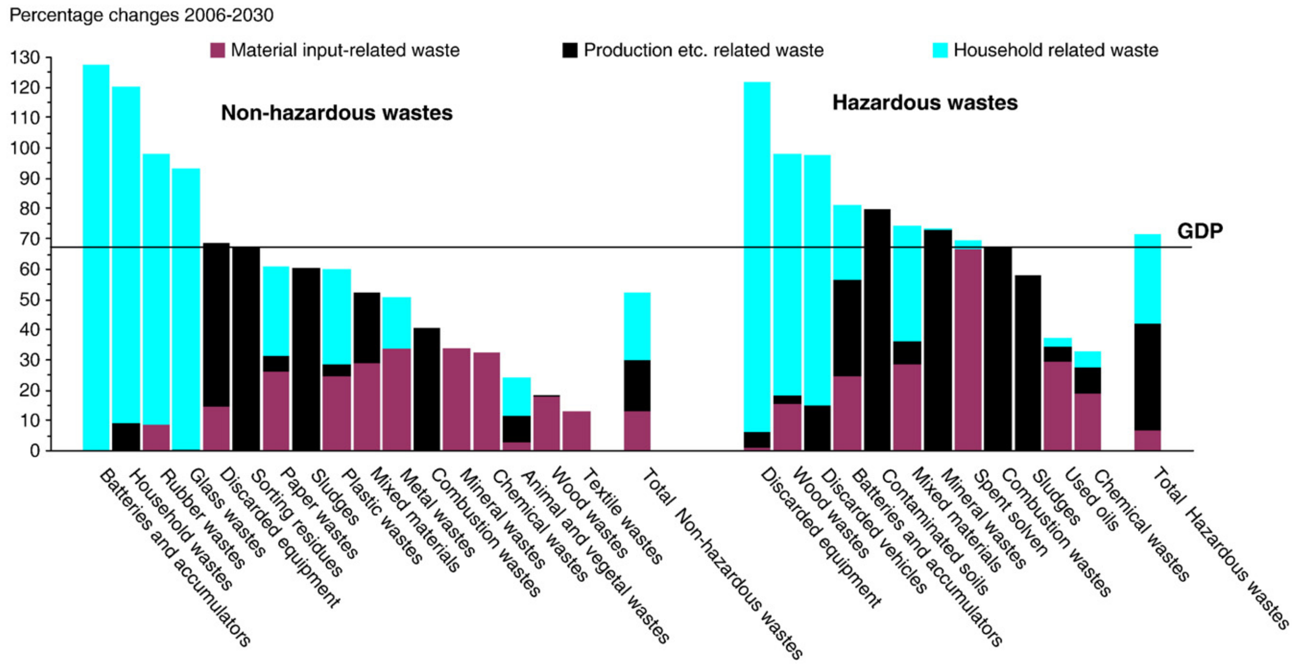

Fig. 1. Generation of non-hazardous and hazardous wastes by driving forces and compared to GDP in the Base line scenario.

development of non-hazardous wastes: Total non-hazardous waste grows by 52% compared to 72% for hazardous waste. In terms of growth of hazardous waste, both overall and when looking at the individual waste types, firms' production is a more significant source compared to what is shown for non-hazardous waste. However, households' waste generation is also here dominating among the waste types with the highest growth rates 2006–2030, i.e. 'Discarded equipment', 'Wood wastes' and 'Discarded vehicles'.

The relative decoupling of waste from economic growth is illustrated in Fig. 1 by relating the growth of non-hazardous and hazardous waste, respectively, to the GDP growth (indicated by a solid line in the figure). The relative decoupling of non-hazardous waste generation, measured by the difference in growth between total non-hazardous waste and GDP, will be 15 percentage points according to the 'Baseline scenario', since GDP is expected to grow by 67% over the period. Only a few non-hazardous waste types ('Batteries and accumulators', 'Household wastes', 'Rubber wastes' and 'Discarded equipment') increase faster than GDP and thus a relative decoupling of waste generation from economic growth is only noted for the other non-hazardous waste types. The picture of hazardous waste growth in relation to GDP growth looks different from that noted for non-hazardous waste growth: Total hazardous waste grows faster than GDP and only three out of twelve hazardous waste types are noted for a relative decoupling ('Chemical wastes', 'Used oils' and 'Sludges'). The sources with constant waste intensities (household consumption and firms' production) are mostly dominating in generating hazardous wastes, but the three decoupling waste types are dominated by the source with decreasing waste intensities (firms' material input) or relate to a declining production sector, in the case of 'Sludges'.

By applying historical waste intensities to the 'Baseline scenario', which, again, is an official projection of the Swedish economy until 2030, we can observe relative but not absolute decoupling of waste quantities. This development does not comply with the Government's target of non-increasing waste quantities in the future, i.e. absolute decoupling of waste generation from economic growth. For future waste generation to decouple from economic growth, in relative or absolute terms, a change in favour of less waste-intensive products must occur and/or the waste intensities in economic and human activities must decrease. The waste intensities in economic activities decrease when technology develops in the direction of saving on waste-generating inputs, as then production processes become less waste generating. The waste intensities of human activities can decrease because of changes in consumer behaviour. Technological change and consumer behaviour are affected in this direction when waste generation is made relatively dearer than material saving. This can take place due to (expected) future price changes. However, to attain the Government's target of non-increasing waste quantities, policy measures should be taken if there is a lack of future price changes in the desired direction or in act to reinforce the effect of such future price changes.

The strength of a policy measure in terms of its effect on waste generation is difficult to estimate. However, the combined effect of price changes and policy measures necessary to achieve absolute waste decoupling can be estimated, as suggested here, by comparing historical waste intensities and the future waste intensities necessary to produce absolute waste decoupling. To attain absolute waste decoupling, the effect of economic growth on waste generation must be offset by reduced waste intensities in economic and human activities. On an aggregated level, reductions of waste intensities are reflected in the changes of waste intensities related to material, production and households, respectively, from 2006 to 2030 in the 'Baseline' and the 'Decoupling' scenarios. The respective changes in the intensities of non-hazardous and hazardous wastes related to material, production or household for the period are shown in Table 2.

For the 'Baseline scenario', these changes are based on the historical estimates reported in Section 3. We assume only the material-related waste intensities to decrease, whereas the intensities related to production and households are assumed to remain unchanged during the period. While these assumed changes counteract the influence of economic growth on generation of non-hazardous wastes, which is noted for a relative decoupling in Fig. 1, they do not affect the influence on generation of hazardous wastes. However, an absolute decoupling of any of the non-hazardous or hazardous waste types cannot be observed in the 'Baseline scenario';

Table 2
The scenario waste intensities.

	Baseline scenario	Decoupling scenario
Non-hazardous waste		
Material related	−1	−2.16
Production related	0	−1.35
Household related	0	−3.36
Hazardous waste		
Material related	−1	−2.03
Production related	0	−2.09
Household related	0	−3.36

closest comes the quantity of ‘Animal and vegetal wastes’ related to material inputs as shown in Fig. 1.

3.2. Decoupling Scenario

To set up the ‘Decoupling scenario’, we decrease the waste intensities of the ‘Baseline scenario’ for the various types of non-hazardous and hazardous wastes in order to achieve absolute decoupling in the generation of wastes related to material, production and households, respectively. In this way, we will have an absolute decoupling also for total non-hazardous and total hazardous wastes. The procedure allows for different reductions of the waste intensities related to material, production and households, respectively. In addition, it allows for the reductions to differ between non-hazardous and hazardous waste intensities. In all, we will have six waste intensities, which differ between the ‘Baseline scenario’ and the ‘Decoupling scenario’ as shown in Table 2.

By modelling the absolute decoupling in this manner for the waste intensities related to material, production and households, we link the decoupling issue to the main driving forces behind waste generation: technical change, economic growth and household consumption. An absolute decoupling from economic growth demands significant reductions of the waste intensities linked to these three forces. This can be concluded by comparing the yearly reductions in the ‘Decoupling’ and ‘Baseline’ scenarios shown in Table 2 in light of the economic growth rate of 2.2% per year from 2006 to 2030. To offset the effect of economic growth on waste generation in the ‘Decoupling scenario’, the intensities of input-related wastes must be reduced at a yearly rate of a full 2% for both non-hazardous and hazardous wastes. This is about twice the historical yearly reduction rate of 1% used in the ‘Baseline scenario’. For the waste intensities related to production, the reduction rates are 1.35 and 2.09% for non-hazardous and hazardous wastes, respectively, in the ‘Decoupling scenario’. These reduction rates should be compared to our assumption of unchanged waste intensities from 2006 to 2030 in the ‘Baseline scenario’. In order to attain absolute decoupling, the production-related intensities need to be reduced more for hazardous than for non-hazardous wastes, since the fast-growing production sectors account for a larger share of the former. The intensities of household-related wastes decrease by 3.36% per year in the ‘Decoupling scenario’ for both non-hazardous and hazardous wastes. This figure comes close to the figure of the growth rate for private consumption in the scenarios, in order to counteract the growth effect of private consumption on generation of household-related wastes. It, however, falls far below the unchanged waste intensities used in the ‘Baseline scenario’. For model specific reasons, the growth effect is counteracted for all the types of household-related wastes, and therefore no blue bars are depicted in Fig. 2.

Although absolute decoupling is attained for total non-hazardous and total hazardous wastes, this is not the case for all the various types of wastes as shown by the bars depicted in Fig. 2. We observe relative decoupling for all waste types, compared to the GDP growth of 69%, but absolute decoupling for 7 out of 17 non-hazardous waste types and for 3 out of 12 hazardous waste types. The reductions of material- and household-related wastes contribute in a significant way to the absolute decoupling of non-hazardous wastes. All eight household-related non-hazardous waste types shown in Fig. 1 are noted for an absolute decoupling in Fig. 2. A more significant impact of production-related wastes than of material-related wastes is observed in the decoupling of hazardous waste types, and here, also all eight household-related hazardous wastes types are noted for an absolute decoupling. The large increases of production-related waste observed for the non-hazardous waste types ‘Discarded equipment’, ‘Sorting residues’, ‘Sludges’ and ‘Mixed materials’ are counteracted by significant reductions of material-related waste labelled ‘Glass wastes’, ‘Wood wastes’ and ‘Textile wastes’, but also by a reduction of production-related wastes labelled ‘Animal and vegetal wastes’. For hazardous wastes, reductions of production-related waste labelled ‘Discarded vehicles’ and ‘Sludges’ and of material-related waste labelled ‘Chemical wastes’ counteract increases in material-related waste labelled ‘Spent solvents’, ‘Mixed materials’, ‘Wood wastes’ and in other waste types.

4. Concluding Remarks

The strength of the policy measures needed to attain Sweden's environmental objective of non-increasing future waste quantities is here illustrated by the waste intensity outcomes in a ‘Decoupling scenario’ compared to those in a ‘Baseline scenario’ of the Swedish economy 2006–2030. Waste generation is from a historical point of view closely related to economic growth and for an absolute decoupling (i.e. no waste growth) waste generation by firms and households must decrease in relation to their economic activities in the future. We address this aspect by letting firms' technology and households' behaviour differ, with respect to the waste intensities of their economic activities, between the ‘Baseline scenario’ and the ‘Decoupling scenario’. Relative decoupling (i.e. less waste growth than economic growth) is here measured by relating growth in waste generation to GDP growth. In the ‘Baseline scenario’, a relative decoupling is noted for 11 out of 17 non-hazardous waste types as well as for total non-hazardous wastes. The picture of hazardous waste growth looks different from that noted for non-hazardous waste growth. Total hazardous waste grows faster than GDP and only 3 out of 12 hazardous waste types are noted for relative decoupling.

An absolute decoupling cannot be observed in the ‘Baseline scenario’ for any of the non-hazardous or hazardous waste types. In this scenario, we assume only the material-related waste intensities to decrease, whereas the intensities related to production and households are assumed to remain unchanged from 2006 to 2030. When setting up the ‘Decoupling scenario’, we decrease these waste intensities in order to achieve absolute decoupling in the generation of wastes related to material, production and household, respectively. By modelling absolute decoupling in this manner, decoupling is linked to the main driving forces behind waste generation: technical change, economic growth and household consumption.

Absolute decoupling from economic growth demands significant decreases of the waste intensities linked to these three drivers. To offset the effect of economic growth on waste generation in the ‘Decoupling scenario’, the intensities of material-related wastes must decrease at a yearly rate that is about twice the historically grounded reduction rate of 1% used in the ‘Baseline scenario’. Also, for the waste intensities related to production and households, the reduction must be significant in the ‘Decoupling scenario’ compared to the ‘Baseline scenario’ and historical estimates. These necessary reductions of waste intensities introduced in the ‘Decoupling scenario’ serve, in our analysis, as an illustration of the strength of the policy measures needed to attain Sweden's environmental objective of absolute decoupling between economic growth and waste generation in the future. An alternative waste management policy that concentrates primarily on reducing hazardous wastes could be argued for, when focusing on the environmental costs of waste generation. Also, in this

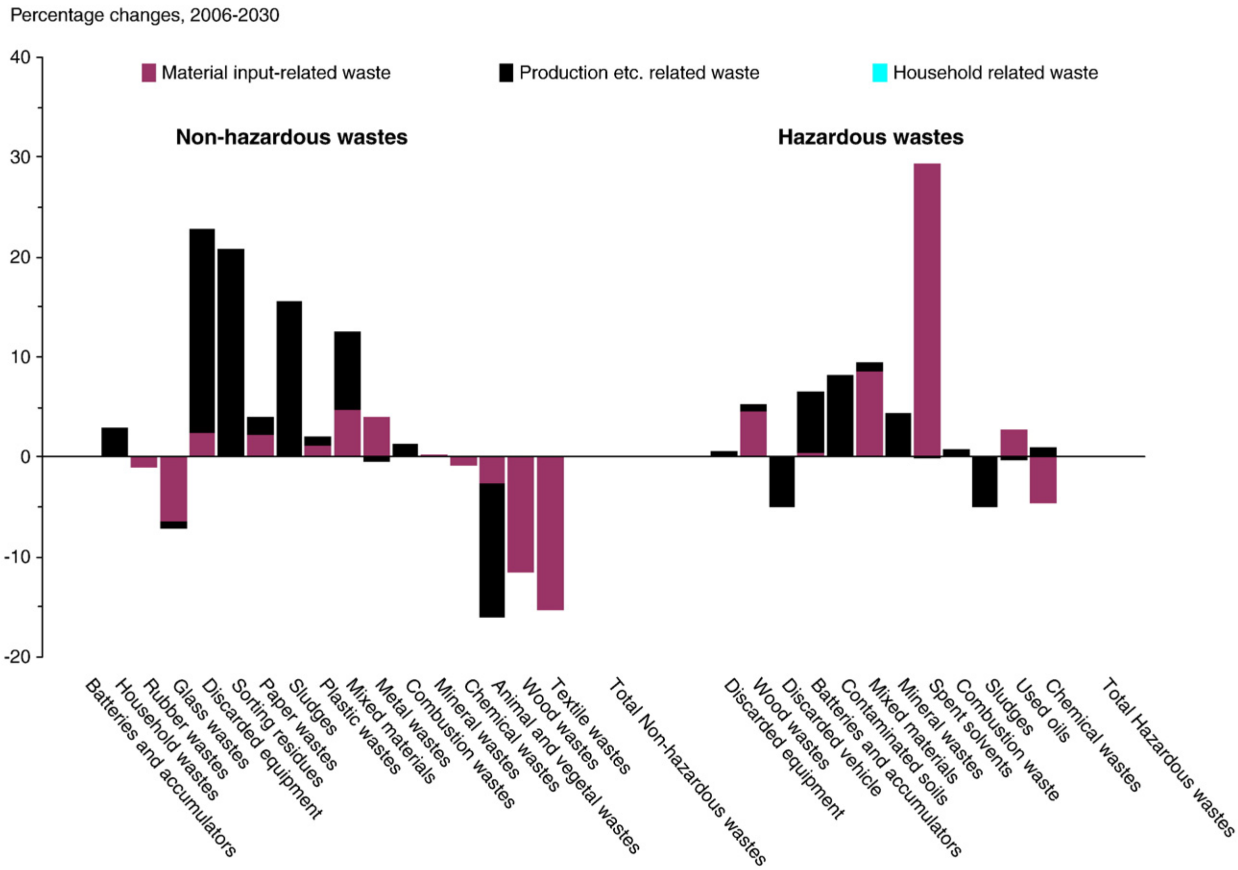

Fig. 2. Decoupling of non-hazardous and hazardous wastes by driving forces.

case, the policy measures must have a considerable strength according to our findings. In fact, we find that the production related waste intensities need to be reduced even more for hazardous than for non-hazardous wastes in order to attain an absolute decoupling between economic growth and waste generation.

To reduce waste intensities linked to firms, the policy instruments introduced must bring about an introduction of waste preventing production techniques. For example, an introduction of virgin material taxes could affect production techniques in such a direction. Also according to our findings, it seems that policy instruments must affect households in the direction of less waste intensive behaviour. 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.

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