This article is reproduced by kind permission of CIWM and IWM Business Services. www.ciwm.co.uk
Communications in waste and resource management, Vol.8(1), 2007, p.12-18

Coupling Hidden Flows and Waste Generation for Enhanced Materials Flow Accounting

Thomas Raffield[a,b], Martin Herben[b], Stephen Billington[b],
Phil Longhurst[a] and Simon Pollard[a]*

[a]*Centre for Resource Management and Efficiency, Sustainable Systems Department, School of Applied Sciences, Cranfield University, Bedfordshire, MK43 0AL, UK*
[b]*Enviros Consulting Ltd, Culham Science Centre, Oxfordshire, OX14 3DB, UK*

[*]*Corresponding author: email: s.pollard@cranfield.ac.uk, phone: +44 (0)1234 75410, fax: +44 (0)1234 751671*

ABSTRACT

We present an adaptation of an existing materials flow model to account for waste flows in the domestic environment. The revised approach offers added functionality for economic parameters that influence waste production and disposal. Hypothetical waste and resource management futures illustrate the utility of model. A sensitivity analysis confirms that imports, domestic extraction and their associated hidden flows impact mostly on wastes generation. The model offers enhanced utility for policy and decision makers with regard to economic mass balance and strategic waste flows.

KEYWORDS

Resource management, material flow, modelling, accounting, waste

1. INTRODUCTION

An essential contribution to informed policy decisions on waste and resource management is the analysis of the materials flow within an economy. Several authors (Matthews et al, 2000; Hendricks et al, 2000; Bringezu and Schütz, 2001a, b; EUROSTAT 2001; 2002; Bringezu et al, 2003; 2004; Longhurst et al, 2005; Mutha at al, 2006; Dahlström and Ekins 2006a, b) have developed mass balance models based on the principles of industrial ecology, and present important insights into resource efficiency and productivity in industrialised economies.

One objective of these studies has been to evaluate the decoupling of economic growth from waste production (Defra, 2002). Though reasonably resource efficient, the UK economy makes a considerable demand on materials use (Bringezu and Schütz, 2002). Officer (2007) reports the real gross domestic product (GDP) of the UK in 2005 as £1.17 x 106m and, with a growth rate of c3% per annum (Asif and Muneer, 2007), this is one of the fastest in Europe. Sheerin (2002) reports a UK materials input (total materials requirement for the economy) of 35.1 tonne (t) per capita. The Royal Society for Wildlife Trusts (2006) estimate a UK ecological footprint of 5.4gha (global hectares - an area of productive land or sea required to produce the resources consumed and absorb the wastes generated in an economy) per capita, compared to a global average of 2.2gha per capita, exceeding the available global biocapacity of 1.8gha per capita.

Several studies have quantified resource flows and their associated impacts in the context of waste management (Matthews et al, 2000; Hicks et al, 2004; Zhao et al, 2005; Jose et al, 2005; Longhurst et al, 2005). In an influential study, Matthews et al, (2000) present a comprehensive account of materials flow modelling and detail a number of critical materials flows to which the reader is referred. Adapting their approach, we present a materials flow model for the UK that couples hidden and waste flows. We introduce and test a strategic waste flow element to the model (Raffield, 2006; Figure 1), that can be used to explore hypothetical scenarios on waste and resource futures.

2. METHODOLOGY

Key model variables are presented in Table 1. The direct material input (DMI; Figure 1) is the principal variable representing material tonnage into the economy. The relationships between DMI and other variables enables the model to express the onward fate of the

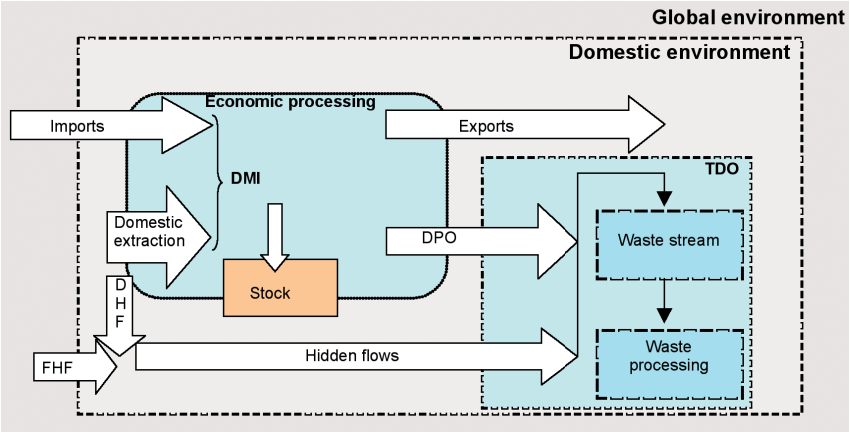

Figure 1: The advanced materials flow model (after Matthews et al., 2000; Raffield, 2006)

Input or output flow	Flow name	Symbol	Flow description
I	Imports	Q_i	Imported materials from abroad
I	Domestic extraction	Q_{de}	Domestically extracted materials
I and O	Foreign hidden flows (FHF)	Q_{fhf}	Foreign hidden flows entering the domestic environment with the imports, e.g. loose soil and foliage attached to timber
I and O	Domestic hidden flows (DHF)	Q_{dhf}	Domestic hidden flows, e.g. mining overburden or the dust like material from aggregate crushing that has no utility.
I and O	Hidden flows	Q_{hf}	Total of both foreign and domestic hidden flows
I	Net addition to stock	Q_{nas}	Additions to stock that occur within the economy and domestic environment.
O	Domestic processed output (DPO)	Q_{dpo}	Materials used in the economy and then flow to the domestic environment. Include wastes and emissions. Materials recycled would be deducted from this output.
O	Exports	Q_e	Exports out to other countries. This waste is assumed not to have an impact on the domestic environment
I	Direct material input (DMI)	DMI	Total material input into the economy from both domestic and foreign sources
I	Total material requirement (TMR)	TMR	The total amount of material entering the domestic environment including hidden flows (TMR = DMI + $Q_{hf)}$
-	Initial stock	Initial S	The initial level of stock in the economy and domestic environment
-	Total stock	Total S	The total level of stock in the economy and environment after any net additions(= Initial S + Q_{nas})
O	Total domestic output	TDO	The total output to the domestic environment including waste, emissions and hidden flows (= Q_{dpo} + Q_{hf})
O	Total material output	TMO	The total output of materials from all sources including exports (= TDO + Q_e)

Table 1: Key model variables (adapted from Matthews et al, 2000)

DMI in million tonnes (Mt) per unit time as material is used for economic processing, in manufacturing, for example.

Flows in the model were constructed in consecutive Excel™ spreadsheet layers where variables can be altered. To model the constituent components of the DMI and the onward fate of materials as output flows, a number of additional variables were incorporated, adapting Bringezu and Schütz, (2002) and Enviros Consulting Ltd, (2006) (Table 2). For quality control, sheets with underpinning assumptions were "locked" and preconditions set (Table 2) to ensure input data was consistent. For example, the precondition of securing a mass balance throughout.

A fundamental assumption of this approach is described by Matthews et al, (2000). Hidden flows enter the domestic environment from foreign imports and domestically extracted materials (Figure 1). They include domestic material such as mining overburden, eroded soil and ancillary substances extracted coincidently with the desired resource (coal, sand and gravel, clay etc) and accumulating residues that can become waste. Once hidden flows enter the domestic environment they remain largely unaltered and are represented by a simultaneous input and output (Figure 1). Here, we utilise an adapted model (Matthews et al, 2000) to explore innovative scenarios and secure detailed DPO and TDO outputs including those for specific waste streams. Data were selected from Environment Agency (2006a; Table 3). Sewage sludge was estimated as contributing <1% w/w of the UK waste production and, for the illustrative purposes of simplifying the modelling calculations, assumed to be zero. To expand the utility of the model, it was necessary also to represent wastes disposal routes (Environment Agency, 2006b; Table 4). Input data were used to evaluate a proof of concept and examine a number of hypothetical scenarios. The consistency of model outputs were verified by reference to an

independent parallel analysis (Enviros Consulting Ltd., 2006) and found to be consistent.

3. RESULTS AND DISCUSSION

3.1 Scenario analysis

The utility of the model was illustrated using three scenarios: (i) a UK reference base case; (ii) a UK depleted of domestic resources; (iii) a dramatically reduced UK reliance on landfill. We also discuss a sensitivity analysis, commenting on critical model features. The base scenario input variables are presented in Table 5 and model outputs in Table 6.

The resulting mass output derived from the base calculation is presented in Table 6, acting as a reference for the subsequent scenarios. When a scenario did not require variables to be changed they remained as presented in the base case.

The UK is increasingly reliant on imported resources. We sought to understand the impact of future changes on materials and waste flows over successive time intervals, T1, T2 and T3. Table 7 identifies variables modified from the base case (Table 5).

Model results (Table 8) illustrate the principal change is associated with the FHF as a result of growing imports. Imports increased by

Symbol	Value	Description
Q_i	33%w/w	The amount of the DMI imported for abroad
Q_{de}	67%w/w	The amount of the DMI extracted domestically
Q_{fhf}	2.0 per tonne	The amount of hidden flows that accompany imported materials. For every imported tonne of material there is 2 tonnes of hidden flow
Q_{dhf}	0.6 per tonne	The amount of hidden flows that accompany domestically extracted materials. For every tonne of material there is 0.6 tonnes of hidden flow
Q_{nas}	65%w/w	The amount of the DMI that becomes a net addition to stock (adapted Enviros Consulting Ltd, 2006)
Q_e	8%w/w	The amount of DMI exported to abroad as an output
Q_{dpo}	27%w/w	The amount of DMI that passes out of economic processing as wastes and emissions (adapted Enviros Consulting Ltd, 2006)

Table 2. Values for the base model variables (adapted from Bringezu and Schütz, 2002; and Enviros Consulting Ltd., 2006)

Waste stream	%w/w contribution
Agriculture	20
Mineral	21
Sewage sludge	0 (assumed)
Dredgings	8
Municipal	8
Industrial	13
Commercial	6
Construction and demolition	24
Total	434 Mt per annum

Table 3. Waste streams incorporated into the base models (after Environment Agency, 2006a)

Waste / route %w/w	Landfill	Energy recovery	Recycled	Other recovery	Other disposal	Reference
Agriculture	2.0	0.0	0.0	0.0	98.0	Environment Agency, 2006b
Mineral	30.0	0.0	50.0	0.0	20.0	Environment Agency. 2006b
Sewage sludge	2.9	21.6	0.0	71.0	4.5	Defra, 2006a
Dredgings	0.0	0.0	0.0	0.0	100	Morris, 2006
Municipal	75.0	9.0	16.0	0.0	0.0	Environment Agency, 2006b
Industrial	35.1	3.5	35.0	15.1	11.3	Defra, 2006b
Commercial	47.9	3.9	30.9	6.7	10.6	Defra, 2006b
Construction and demolition	30.0	0.0	50.0	0.0	20.0	Environment Agency, 2006b

Table 4. Waste streams and disposal routes for the base model (Environment Agency, 2006b, Defra 2006a, b and Morris, 2006)

Variable	Value	Reference
Qi / I	33%	Bringezu and Schütz (2002)
Qde / DE	67%	
Qnas / Split_NAS	65.0%	Adapted from Enviros Consulting Ltd. (2006)
Qe / Split_Exp	8.0%	
Qdpo / Split_DPO	27.0%	
DMI / DMI_Time	1508 Mt	
Qdhf / DHF_ton	0.6 tonnes / tonne	Bringezu and Schütz (2002)
Qfhf / FHF_ton	2.0 tonnes / tonne	

Table 5. Variables for the base case (after Enviros Consulting Ltd., 2006; Bringezu and Schütz, 2002

Variable	Total (Mt) over three time periods
Imports	14923
Dom. extraction	3031
FHF	2986
DHF	1817
Exports	362
DPO	1222
TDO	6026
NAS	2941
Landfill	1647
Energy recovery	85
Recycled	1819
Other recovery	143
Other disposal	2333

Table 6: Model output for the base UK scenario

461Mt over the time period with a consequent impact on FHF of +940 Mt. FHF make up 62.3% of the original DMI and could surpass this figure if the trends continued. Domestic extraction fell by 467Mt, equating to a drop of 281mt for the DHF, reflecting current UK trends (Sheerin, 2002). As a result of these combined effects, TDO increased by 659 Mt with a total over time of 8346Mt, > 39% greater than that produced for the base case.

tA growth in imports increases foreign hidden flows (FHF) that must be treated and disposed of within the UK (Table 8). The UK environment, already strained due to the extraction of the remaining resources, has added pressure from the escalating TDO as a result of FHF attributed to imports. Unless trading partners increase their extraction efficiency or ensure their resources are of a higher quality prior to export, then the UK continues to see an increase in FHF and the associated environmental pressures. The impacts of this scenario will not only be felt in the UK because by becoming increasingly dependant on imports, we place increased environmental burdens on our trading partners.

The statutory instruments introduced in response to the requirements of the EU Landfill Directive and, specifically, the diversion targets for biodegradable municipal waste (BMW) introduced under the Landfill Allowance Trading Scheme allow construction of scenario representing a reduced reliance on landfill (Table 9). The economic variables remained as for the base case. According to Europa (2004), BMW accounts for between 60%w/w and 70% w/w of municipal solid waste and, as such, the change in the landfill variable was based on assumption over three successive time intervals and the targets identified above.

Variable	Time			Reference
	T1	T2	T3	
Dom. extraction	**45.0%**	**31.2%**	**14.0%**	**adapted** FROM DTI (2003)
Imports	**55.0%**	**68.8%**	**86.0%**	

Table 7. Variable for the UK running out of domestic resources scenario

Table 10 highlights the changes in model output. With the exaggerated targets in place, the amount of municipal waste going to landfill decreased by 68.2 Mt while other disposals increased commensurately. The overall tonnage of waste in other disposal and therefore diverted from landfill was 234 Mt, without discussion (here) of other treatment or disposal options.

tStrictly hypothetical, the output provides rudimentary insight however into the challenges the UK faces with respect to waste and resource management infrastructure. Simplistically, if energy-from-waste was adopted for 234 Mt of diverted waste (Table 10), assuming incineration facilities were large with an average capacity of 0.7 Mt/annum, then 334 such facilities would be required, with a significant density of plant likely to be required in central city areas (Longhurst et al., 2005). More usefully however, with the option to incorporate and modify a range of waste and resource management options in response to landfill diversion targets, the revised approach now has improved utility as a strategic planning tool.

3.2 Sensitivity analysis

A comprehensive sensitivity analysis is presented in Raffield (2006). This analysis processed the base case parameters with the waste streams and disposal pathways excluded as they are not main drivers of the model and fluctuate in response to the DPO. For ease, parameters on the economic side of the model were altered, in turn, applying a 10% increase on the base case parameter value (Table 11) and the knock-on influences on other parameters examined.

tThe direct material input (DMI)

has most influence on the other parameters (Table 11). A 10% increase in DMI (a total material variance of 642 Mt) resulted in increases to domestic extraction (+100 Mt) and TDO (+200 Mt). Similar increases to imports and domestic extraction (Table 11) have a direct impact on hidden flows (DHF and FHF). The domestic economy parameters (NAS, DPO and exports) are influenced by the DMI, irrespective of the percentage share of DMI they account for. The only other parameter these variables impact upon was the TDO.

The sensitivity analysis supports the trends that emerge from the scenario modelling. Hidden flows (DHF and FHF) are sensitive to changes in key materials flow (Matthews et al., 2000; Sheerin, 2002). TDO rises are important and increase if DMI grows in parallel. DMI is the most influencing parameter, but when accompanied by changes in other parameters the results are often dramatic. Overall, the model parameters are interdependent and while one parameter change will not see a significant shift in results, a change in a combination of sensitive parameters can lead to the most significant variances.

3,3 Model limitations and developments

Although the model was constructed as closely as possible to the materials flow process, there were features excluded due to their complexity. Matthews et al. (2002) included air and water as part of the material flows that were excluded here. Furthermore NAS should take into account a certain degree of outflow due to end-of-life products and buildings lost from the chain of utility as wastes. Both these factors were considered too complex to model at the proof of concept stage and their representation therefore needs to be accounted for in future developments. Additional improvements could include accounting for dynamic decay in stock, so that an inward and outward flow could be attributed, providing a more representative account. With additional sophistication, waste treatment capacity, emissions and carbon and energy flows (Uihlein et al, 2006; Biffaward, 2002) could all be incorporated.

Variable	Time PERIOD TOTALS (MT)			Total (MT)	Change (MT)
	T1	T2	T3		
Imports	**829**	**1030**	**1290**	**3149**	+ 461
Domestic extraction	**678**	**500**	**211**	**1389**	- 467
FHF	**1650**	**2070**	**2590**	**6310**	+ 940
DHF	**407**	**282**	**126**	**815**	- 281
TDO	**2464**	**2759**	**3123**	**8346**	+ 659

Table 8. Results for UK running out of domestic resources scenario

Variable	Time			Reference
	T1	T2	T3	
Municipal – landfill	**48.7%**	**24.4%**	**6.1%**	**adapted** from Europa (2004) the BMW in the MSW was reduced by 50% w/w and then **75%** w/w to exaggerate the reduction required
Municipal – other disposal	**26.3%**	**50.6%**	**68.9%**	**The** reduction in landfill waste was placed into this category so the change in tonnage could be represented

Table 9: Variables for a reduced reliance on landfill

Variable	Time Period Totals (mt)			Total (MT)	Change (MT)
	T1	T2	T3		
Municipal – landfill	**78.2**	**38.8**	**10.0**	**127.0**	- 68.2
Municipal – other disposal	**42.2**	**80.8**	**111.4**	**234.0**	+ 68.2

Table 10: Model output for the change in legislation for the UK

4. CONCLUSIONS

The ability to link economic trends, hidden flows and waste generation provides additional utility to the work of Matthews et al (2000). We offer a proof of concept for these modest amendments and an initial demonstration of utility by references to three hypothetical scenarios. The amendments have utility across a range of scales. Future advancements could include implementing a decay function to the materials stock and the incorporation of flows for air and water. Specific waste streams could be further evaluated and reuse/disposal routes modelled, allowing the model to explore a range of scenarios for the new waste technologies.

5. ACKNOWLEDGEMENT

This research was funded by Enviros Consulting Ltd. We are grateful to Dr Surabhin Chackiath (Cranfield University) for discussions on model development. The views expressed are the authors' alone.

6. REFERENCES

Asif M and Muneer T (2007) Energy supply, its demands and security issues for developed and emerging economies, *Renew.*

Parameter	Model Parameters	Base case (Mt)	With 10% change (Mt)	Variance (Mt)
Imports from 33.0 to 36.5%	Imports	497	547	+ 50
	Dom. extraction	1010	960	- 50
	FHF	995	1090	+ 95
	DHF	606	549	- 30
	NAS	980	980	0
	Exp	120	120	0
	DPO	407	407	0
	TDO	2000	2070	+ 70
Total Variance (Mt) (positive and negative)				295
Dom. Extraction from 67.0 to 73.7%	Imports	497	396	- 101
	Dom. extraction	1010	1110	+ 100
	FHF	995	793	- 202
	DHF	606	666	+ 60
	NAS	980	980	0
	Exp	120	120	0
	DPO	407	407	0
	TDO	2000	1867	- 133
Total Variance (Mt) (positive and negative)				596
DHF from – 0.6 to 0.66 tonne/ tonne	Imports	497	497	0
	Dom. extraction	1010	1010	0
	FHF	995	995	0
	DHF	606	666	+ 60
	NAS	980	980	0
	Exp	120	120	0
	DPO	407	407	0
	TDO	2000	2060	+ 60
Total Variance (Mt) (positive and negative)				120
FHF from 2.0 to 2.2 tonne/ tonne	Imports	497	547	0
	Dom. extraction	1010	960	0
	FHF	995	1090	+ 95
	DHF	606	606	0
	NAS	980	980	0
	Exp	120	120	0
	DPO	407	407	0
	TDO	2000	2100	+ 100
Total Variance (mt) (positive and negative)				195
Exports from 8.0 to 8.8%	Imports	497	497	0
	Dom. extraction	1010	1010	0
	FHF	995	995	0
	DHF	606	606	0
	NAS	980	980	0
	Exp	120	132	+ 12
	DPO	407	395	- 12
	TDO	2000	1990	- 10
Total Variance (Mt) (positive and negative)				34
NAS from 65.0 to 71.5%	Imports	497	497	0
	Dom. extraction	1010	1010	0
	FHF	995	995	0
	DHF	606	606	0
	NAS	980	1070	+ 90
	Exp	120	120	0
	DPO	407	309	- 98
	TDO	2000	1010	- 90
Total Variance (Mt) (positive and negative)				278
DPO from 27.0 to 29.7%	Imports	497	497	0
	Dom. extraction	1010	1010	0
	FHF	995	995	0
	DHF	606	606	0
	NAS	980	939	- 41
	Exp	120	120	0
	DPO	407	447	+ 40
	TDO	2000	2040	+ 40
Total Variance (Mt) (positive and negative)				121
DMI from 1508 to 1658.8 mt	Imports	497	547	+ 50
	Dom. extraction	1010	1110	+ 100
	FHF	995	1090	+ 95
	DHF	606	666	+ 60
	NAS	980	1070	+ 90
	Exp	120	132	+ 12
	DPO	407	447	+ 40
	TDO	2000	2200	+ 200
Total Variance (Mt) (positive and negative)				642

Table 11: Summary of sensitivity analysis

Sustain. Energ. Rev. 11, 1388-1413.

Bringezu S and Schütz H, (2001a) Material use indicators for the European Union, 1980-1997. Economy-wide material flow accounts and balances and derived indicators of resource use. EUROSTAT Working Paper 2/2001/B/2. Wuppertal Institute, Germany.

Bringezu S and Schütz H (2001b) *Total material requirement of the European Union.* Technical Report 56. European Environmental Agency, Copenhagen, Denmark.

Bringezu S and Schütz H (2002) Resource use and efficiency of the UK economy, Prepared by Wuppertal Institute for Department for Environment, Food and Rural Affairs, London, UK.

Bringezu S, Schütz H and Moll S (2003) Rationale for and interpretation of economy-wide materials flow analysis and derived indicators, *J. Ind. Ecol.* 7, 43-64.

Bringezu S, Schütz H, Steger S and Baudisch, J (2004) International comparison of resource use and its relation to economic growth : the development of total material requirement, direct material inputs and hidden flows and the structure of TMR, *Ecol. Econ.* 51, 97-124.

Dahlström K and Ekins P (2006a) Eco-efficiency trends in the UK steel and aluminum industries: differences between resource efficiency and resource productivity, *J. Ind. Ecol.* 9, 171-188.

Dahlström K and Ekins P, (2006b) Combining economic and environmental dimensions: value chain analysis of UK iron and steel flows, *Ecol. Econ.* 58, 507-519.

Defra (2002) *Resource use and efficiency of the UK economy*. A Report by the Wuppertal Institute for the Department of Environment, Food and Rural Affairs, Defra, London, UK.

Defra (2006a) E-Digest of environmental statistics: wastes and recycling: sewage sludge. http://www.defra.gov.uk/environment/statistics/waste/wrsewage.htm. <<accessed 14th July, 2006>>.

Defra (2006b) E-Digest of environmental statistics: industrial and commercial waste arisings by waste type and management method, 2002. http://www.defra.gov.uk/environment/statistics/index.htm. <<accessed 14th July, 2006>>.

DTi (2003) Energy white paper: our future creating a low carbon economy. Department of Trade and Industry, The Stationery Office, London, UK

Environment Agency (2006a). Waste an overview: waste produced by sector in the UK. http://www.environment-agency.gov.uk/commondata/103196/waste2?referrer=/yourenv/eff/1190084/resources_waste/213982/152399 <<accessed 14th July, 2006>>.

Environment Agency (2006b). Strategic waste management information 2002-3. http://www.environment-agency.gov.uk/subjects/waste/1031954/315439/923299. <<accessed 14th July, 2006>>.

Enviros Consulting Ltd, (2006) Strategic waste and resources think piece. Enviros Consulting Limited, Shrewsbury, UK.

Europa (2004) Biodegradable waste. http://ec.europa.eu/environment/waste/compost/index.htm. European Union information portal. <<accessed 14th July 2006>>

EUROSTAT (2001) *Economy-wide material flow accounts and derived indicators: a methodological guide,* Statistical Office of the European Union, Luxembourg.

EUROSTAT (2002) *Material use in the European Union 1980-2000: indicators and analysis,* Statistical Office of the European Union, Luxembourg.

Hendricks C, Oernosterer R, Müller D, Kytzia S, Baccini P and Brunner P H (2000) Material flow analysis: a tool to support environmental policy decision making, Case studies on the city of Vienna and the Swiss lowlands, *Local Environ. Int. J. Just. Sustain.* 5, 311-328.

Hicks C, Heidrich O, McGovern T and Donnelly T (2004) A functional model of supply chains and waste, *Int. J. Product. Econ.* 89, 165-174.

Jose S C, Mitchell N, Little R and Longhurst P, (2005) *Working to plan or planning to work: testing policy by modelling London's waste.* In: Proc. CIWM Annual Conference, 14th – 17th June 2005, Torbay, Chartered Institution of Wastes Management, Northampton, UK.

Longhurst P, Chackiath S, Mitchell N, Little R and Pollard S (2005) *Modelling London's waste - policy relevant research for multi-level governance.* In: Proc. Waste - the Social Context, Alberta, Canada 11th – 14th May, 2005.

Officer, L. (2006) The annual real and nominal GDP for the United Kingdom, 1086 – 2005, Economic History Services, September 2006, http://www.eh.net/hmit/ukgdp/, <<accessed 23rd April, 2007>>.

Matthews E, Amann C, Bringezu S, Fischer-Kowalski M, Hüttler W, Kleijn R, Moriguchi Y, Ottke C, Rodenburg E, Rogich D, Schandl

H, Schütz H, Van Der Voet E and Weisz H (2000) *The weight of nations: material outflows from industrial economies*, World Resources Institute, Washington DC, USA.

Morris R (2006) *Ports and the Habitats Directive: a UK perspective of port-related dredging*, English Nature, Peterborough, UK.

Mutha N H, Patel M and Premnath V (2006) Plastics materials flow analysis for India, *Resource., Conserv. Recycl.*, 47, 222-244.

Raffield, T (2006) *Modelling materials and waste flows in the domestic economy,* MSc Thesis, Cranfield University, UK

Royal Society for Wildlife Trusts (2006) *The mass balance movement: the definitive reference for resource flows within the UK environmental economy*, Royal Society for Wildlife Trusts, Newark, UK.

Sheerin C (2002) UK Material flow accounting, *Econ. Trend.* 583, 53-61.

Uihlein A, Poganitez W-R and Schebek L (2006) Carbon flows and carbon use in the German anthroposphere: an inventory, *Resource. Conserv. Recycl.* 46, 410-429.

Zhao S, Li Z and Li W (2005) A modified method of ecological footprint calculation and its application, *Ecol. Model.* 185, 65-75.

This article is reproduced by kind permission of CIWM and IWM Business Services. www.ciwm.co.uk

https://dspace.org/

Coupling Hidden Flows and Waste Generation for Enhanced Materials Flow Accounting

Raffield, Thomas; Herben, Martin; Billington, Stephen; Longhurst, Philip J.; Pollard, Simon J. T.

2007-06-01T00:00:00Z

http://dspace.lib.cranfield.ac.uk/handle/1826/2541

Thomas Raffield, Martin Herben, Stephen Billington, Phil Longhurst and Simon Pollard. Coupling Hidden Flows and Waste Generation for Enhanced Materials Flow Accounting Communications in waste and resource management, Communications in waste and resource management, Vol.8(1), 2007, p.12-18

Downloaded from a DSpace repository. https://dspace.org/