

Sustainable Consumption and Production – Development of an Evidence Base

Project Ref.: SCP001 Resource Flows

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Summary Report

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1 Introduction

The full length version of this study is available through Defra and comes in three parts:

- The *first* focuses on general **Material Flow Analysis (MFA) methodologies** and their relevance to the Government's Sustainable Consumption and Production agenda. It **recommends the development of a strategic approach to help decision-makers tackle material flows with the most severe environmental impacts first**.
- The *second* focuses on material flow studies which have been commissioned through the **Biffaward Mass Balance scheme** and provides lessons for the future.
- The *third* reviews existing methodologies that estimate the **“embedded emissions” of imported goods and services**¹. A framework for the development of an **embodied emissions indicator** is proposed to quantify direct and indirect impacts associated with domestic consumption.

Each part of the study is summarised in this short report and designed to inform the development of the **sustainable consumption and production (SCP)**, evidence base in the UK.

SCP came to international prominence as part of Agenda 21² and is now a Key Priority Area of the UK Sustainable Development Strategy. The overriding objective of the UK's SCP programme is to **decouple** economic growth from environmental degradation; this is a process in which the **dematerialisation** and **detoxification** of the UK economy go hand in hand. The UK Government has identified three broad areas for policy action:

- “better **products and services**, which reduce the environmental impacts from the use of energy, resources, or hazardous substances,
- cleaner, more efficient **production** processes (doing more with less), which strengthen competitiveness, and
- shifts in **consumption** towards goods and services with lower impacts” (DEFRA, 2005: 44³).

This is a challenging agenda, the success of which relies on a comprehensive understanding of the way we use of natural resources for different human activities as well as an understanding of the environmental impacts related to these activities from a **lifecycle perspective**. Material Flow Analysis (MFA) is a family of approaches that can be used to provide this understanding; tracking human induced physical flows within and between the economy and the environment and from extraction to disposal. This makes it possible to **take all the impacts associated with production and consumption processes into account, wherever they may occur**. This study provides a set of recommendations on how the Government could **develop a strategic evidence base for Material Flow Analysis and build up a robust and strong evidence base accordingly**.

¹ Including carbon dioxide and other pollutants

² United Nations 1992 Declaration. (UN, 1992).

³ All references are provided in the full version of the study

2 Review of Resource Flow Methodologies

(By Jan Minx, Thomas Wiedmann and John Barrett)

The first part of this study was designed to review the **policy relevance, methodological robustness and data requirements** of different MFA methodologies. Six general MFA methodologies were assessed alongside a selection of hybrid methodologies and UK specific resource flow models that use MFA. One main difference between these approaches is that they are applied on different aggregation levels in the economic and human sphere. Some MFA approaches trace physical flows at the **micro level** covering individual substances such as water or chemicals. Others trace compound flows at the **meso level** comprising individual materials and goods such as timber or furniture. MFA can also be used at the **macro level**, accounting for all physical flows in the economy. A similar distinction between approaches working on the micro, meso and macro level can be made in the economic sphere as shown in Figure 1. Hybrid methodologies such as “hybrid life cycle assessment” combine complimentary methodologies working at different levels. In the full study each methodology is discussed with the UK SCP policy context, the main findings are summarised here.

Figure 1 – Classification of MFA Methodologies

		ECONOMIC SPHERE		
		Micro (Firm, process)	Meso (Sectors)	Macro (Region)
MATERIAL SPHERE	Micro (Substance)	SFA	SFA; EIO/NAMEA	EA
	Meso (Materials)	Company accounting; LCI	EIO/NAMEA; BMFA/MSA	EA
	Macro (Aggregate flows)		PIOA	EMFA

SFA: Substance flow analysis
 LCI: Lifecycle inventories
 EMFA: Economy-wide material flow accounting
 PIOA: Physical input-output analysis
 NAMEA: National accounting matrix including environmental accounts
 EIO: Environmental input-output analysis
 BMTA: Bulk material flow analysis
 MSA: Material system analysis
 EA: Environmental accounts

2.1 Review Results

Because different MFA approaches work on different aggregation levels (see Figure 1), they can inform different policy questions. Therefore, it is the first major finding of the report that they **all have the potential to make a valuable contribution to the SCP evidence base**. The main challenge lies in organising MFA approaches so that they can be used to answer policy questions and help set and assess policy targets.

Figure 2 provides a general overview of the level of information different policies require and the level of detail provided by MFA methodologies. The choice of methodology primarily depends on the policy question under consideration: the more general a policy issue, the more aggregated the information required to inform policy. In turn, the more specific a policy, the more specific the physical information required. Different methodologies can be broadly grouped accordingly by their application to the decision-making process (see Femia and Moll, 2005).⁴ For example Lifecycle Analysis (LCI/A) provides specific information about physical flows associated with the lifecycle of a certain product. This information can be used to establish product standards, to change a certain production process or to ban a certain product, if its lifecycle impacts are perceived as detrimental to the well-being of society. In comparison Environmental input-output analysis (EIO), depicts production and consumption processes on the sectoral level. While its lack of detail makes it unsuitable for devising specific policies on products, it covers all economic activities taking place within a certain region and not only a subset like LCI/As. It is therefore more suited to addressing **structural policies** such as taxes and subsidies etc., which have economy-wide implications.

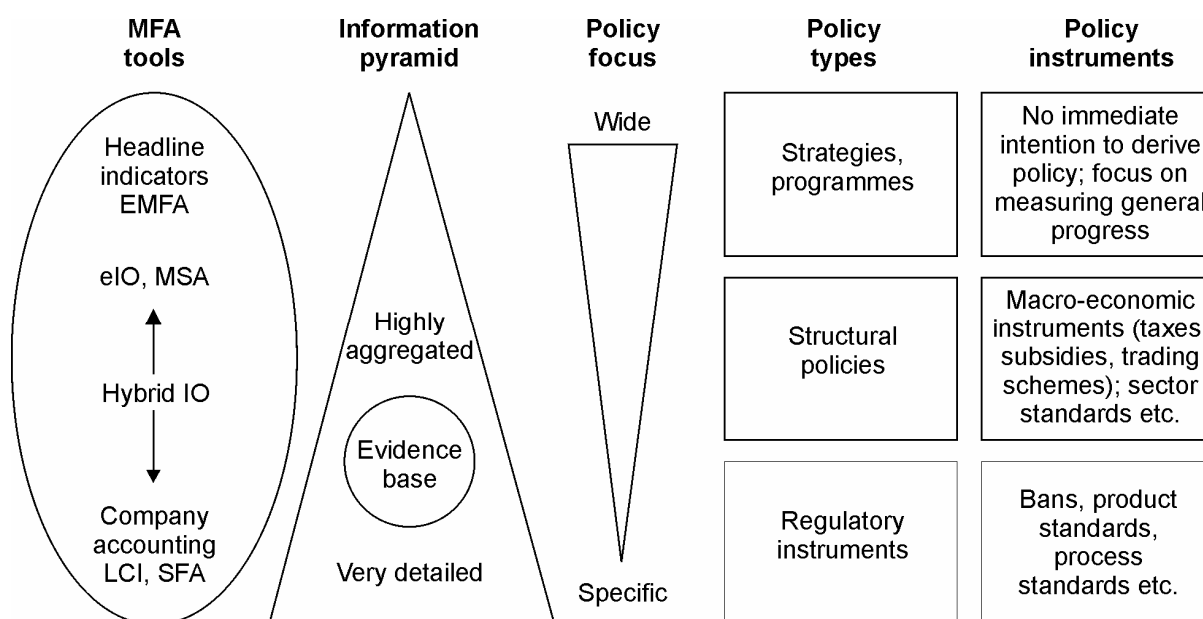


Figure 2 – MFA methodologies in relation to policy demands on different level (adapted from Femia and Moll, 2005)

Beyond this high level assessment of policy relevance it is important to understand that each individual MFA approach has particular strengths and weaknesses. The full study provides specific recommendations on how to overcome these weaknesses for each MFA approach/method. At a more strategic level the government should consider how to:

⁴ The ideas in this Section closely correspond with the ones provided by Femia and Moll (2005).

1. **Ensure good practice:** Some MFA approaches are not sufficiently standardised. Therefore, some limitations can be overcome through the establishment of **methodological guidelines** and **standardised reporting** in line with the government's policy needs. Establishing good practice allows the government to:

- ensure **robustness** and **high quality standards** for individual studies;
- improve **comparability of results** across studies;
- **integrate results** in a higher level data structure, and contribute to the development of an SCP evidence base;
- readily **access** relevant results.

During the 1990s **the Danish Environmental Protection Agency (EPA) established its own reporting guidelines to ensure uniformity and comparability of SFAs undertaken in Denmark.** These guidelines inform methodology, data sources, reliability and confidentiality and present a standard format for the reports. The results of SFAs are used by the EPA and related to the need for instruments, risk minimisation for the substance in question and for the monitoring of policy success in controlling the substance. For the latter some SFAs are updated regularly⁵.

2. **Integrate methodologies:** MFA approaches are sometimes restricted by structural features of their methodological framework. The **robustness** and **applicability** of MFA evidence can be further improved through the integration of methodologies using **hybrid approaches**. The **integration of** the EIOA method as a **top down** approach with the other **bottom-up** methodologies, for example, should be a high priority as it combines the best of two worlds: the complete coverage of the economic system in general and the economic supply chain in particular provided by EIOA approaches and the detailed and problem specific information compiled in bottom-up approaches.

The Japanese Hybrid Waste IO LCA model provides an example of how an integrated methodology can be used to inform policy. While the IO framework provides a complete and detailed meso-perspective on the waste flows in Japan within a certain year, the LCA component allows a focus on particular waste streams, and waste generated over the lifecycle of a product. Used in the UK, this approach would create a single, comprehensive and consistent evidence source to inform the government's sustainable waste agenda. Other methodologies such as BMFA/MSA or SFA can be used in this framework when important data gaps are discovered. SFAs would be applied in the waste context to trace the origin of certain hazardous substances that lead - for example - to problems in their long-term storage or treatment. In later stages such a model could then be further developed to account for regional differences. The ability of the UK to use such a model depends on the quality of waste statistics available. The lack of reliable statistics for commercial and municipal waste has just very recently been pointed out by members of ONS (e.g. Gazley and Francis, 2005). This emphasises the need for a strategic consideration of data.

3. **Collect (necessary) data:** Some limitations are associated with the availability of data in the UK. For Example the UK has not fulfilled its formal commitment to publish analytical input-output tables every five years. The most recent publicly available tables are for 1995 and more recent

⁵ Strict methodological and reporting guidelines in combination with rigid quality control mechanisms are indispensable if the government considers a second wave of studies like those funded through Biffaward

tables are urgently required by the research community. Further improvements of the ONS database in key policy areas such as water, hazardous and toxic substances or land use would also improve the scope and quality of MFA related research⁶.

4. **Consider weight and impact together:** At the heart of the UK SCP agenda is the need to tackle material flows with the most severe environmental impacts first. To support this objective MFA approaches can be extended to address **detoxification** and **dematerialisation** in tandem. Technically this means that MFA methodologies need to consider not only the physical weight but also per unit impact of different material flows. To undertake this, MFA methods can be linked with Impact Potential Approaches (IPAs) as commonly done in life cycle analysis (LCA)⁷. These can **help decision-makers prioritise materials in relation to specific environmental issues such as climate change or acidification**.
5. **Align MFA models to the policy agenda:** The capability of MFA methodologies can be further extended by using them to develop policy scenario models. **Policy scenario models** can be used to inform decision makers on the choice and effectiveness of different policies and to reduce the large uncertainties attached to unknown future states. Among the reviewed MFA methodologies input-output approaches provide the best starting point for scenario development as they allow social, economic and environmental information to be integrated in a consistent data framework (see Keuning, 2000; Stahmer, 2002). This means that human welfare - an ultimate aim of SCP policy - can be adequately represented in a policy scenario using a selection of indicators. Different MFA based tools are already available in the UK for providing this type of policy support (see main report).

2.2 Providing a strategic evidence base

Through the existing MFA approaches there are numerous opportunities to provide policy relevant evidence for individual policy issues. Therefore, the government can pick and choose the methodologies it wants to develop to deal with specific policy issues. This approach may require fewer resources on an individual basis but it does not encourage strategic investment or the development of an evidence base that is flexible enough to inform and aid the development of the far reaching SCP agenda. This indicates the need for a strategic material flow policy approach which is flexible enough to deal with the actual use of all materials – as raw materials, as products and as waste. **It is recommended that the Government develops a strategic material flow approach consistent with the main goals and principles of UK SCP policy.**

Such a strategic material flow approach aims to reduce the life cycle impacts of material use from the cradle to the grave irrespective where the impacts occur (see also De Bruyn et al., 2004; Van der Voet et al., 2005) and aims to tackle materials with the most severe environmental impacts first.. This is in line with the Government's approach and that of the European Commission's Thematic Strategy on the Sustainable Use of Natural Resources. A clear strategic focus on material use in this way would allow SCP policies to **complement** rather than interfere with existing environmental policies

⁶ Section 4.12 of the full version of the study demonstrates how some data gaps can be filled

⁷ IPAs carried out in Life Cycle Analysis commonly aggregate individual impacts into larger impact categories such as 'global warming potential' or 'acidification potential'. Not all of these aggregation methods are commonly accepted and the development of a single indicator of aggregate environmental impact was rejected in this study as unsound. This is detailed in the full report together with a recommendation to carry out a review of IPAs and their various impact categories using a multidisciplinary team

which usually target substance releases/emissions directly. Such a strategic approach should be built around three areas:

- **Dematerialisation/ Prevention** – reducing the amount of physical input required per unit of output;
- **Re-use and recycling** – closing the loop and extending the life-span of materials through longer use of materials and increased use of secondary materials;
- **Material Substitution** – using materials with smaller environmental impacts and replacing the environmentally most damaging materials.

Within each of these areas are policy levers that can be used to tackle the most harmful material flows. These can be identified through a step-by-step procedure for prioritising material flows according to environmental impact:

1. **Prioritise environmental problems:** This is a **political decision** and it remains the responsibility of decision-makers to prioritise the different environmental problems on the agenda. Currently climate change, for example, is considered to be one of the most important issues.
2. **Identify key substances:** Once environmental problems are prioritised, physical evidence can be used to prioritise substance flows accordingly.
3. **Prioritise materials (natural resources, goods, wastes):** For a strategic division of SCP material flow policies, it is important to link the substance releases ultimately causing the various environmental problems to the flows of materials and goods in the economy.
4. **Identify key policy intervention points/ key activities:** Different MFA methodologies can be used to help identify where the most important flows of materials and goods (and therefore also embedded problem substance flows) occur throughout the economy and therefore where they might be best tackled throughout the domestic economic system.
5. **Identify most effective policy instruments:** MFA evidence can be applied in policy analysis models to identify the most efficient and effective policy instruments for tackling key environmental flows for the government’s SCP agenda.

This 5 step process is illustrated in figure 3:

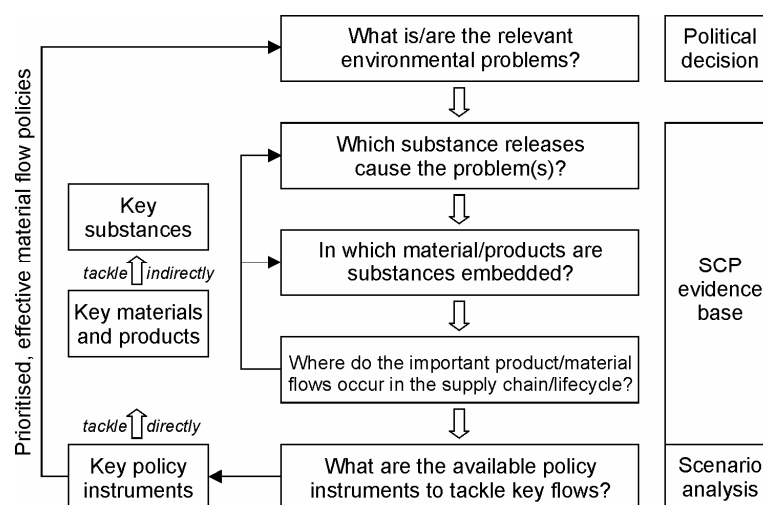
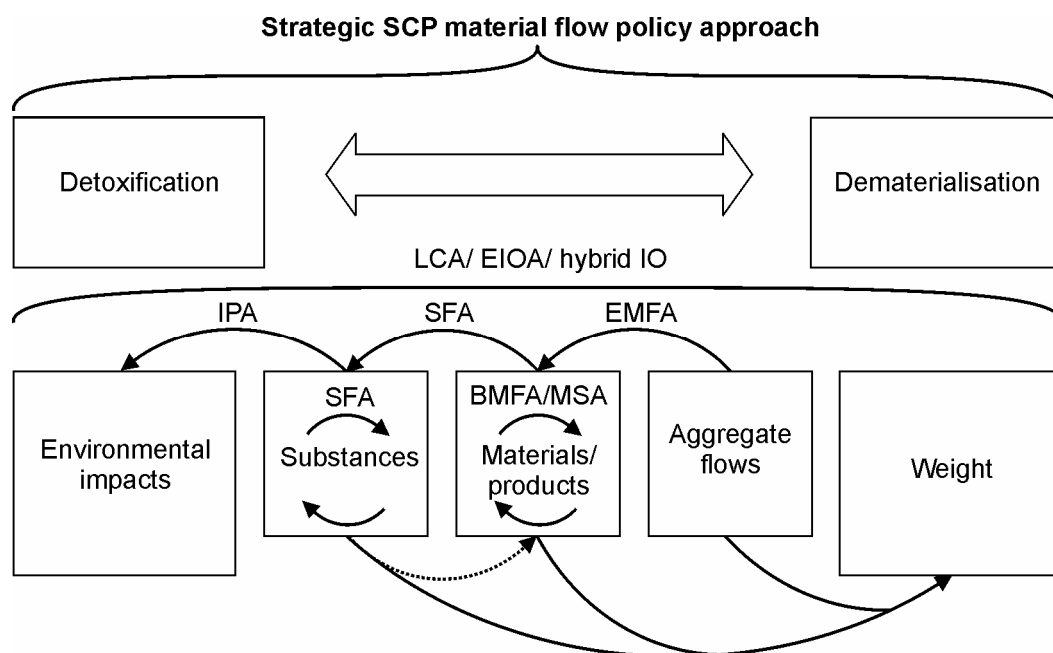


Figure 3 – Framework for prioritising SCP material flow policies

For this prioritisation process to work effectively it needs to be integrated into a single comprehensive methodological approach. This means that a strategic material flow policy approach would be based on a model or set of models that enable:

- all economic activities and associated physical flows of the system under consideration to be covered. For DEFRA this usually covers the national economy.
- the comprehensive coverage of dematerialisation and detoxification through the establishment of clear links between the different aggregation levels of physical flows – see **figure 4**;
- the coverage of environmental, economic and social information
- the performance of comprehensive scenario analysis in order to identify the most suitable policy instruments to suffice the government’s ambition to jointly consider these issues together in the course of SD and SCP policies (DEFRA, 2005).

The creation of a model of this type will require several methodological frameworks to be linked as well as the use of hybrid MFA approach. This in turn will require Government support and involvement as the model cannot be created immediately and will require a step by step process. Existing MFA models such as Cambridge Econometrics REEIO, the University of Surrey’s Regional Material Flow Accounting Model and the Stockholm Environment Institute’s REAP provide promising starting points.



Environmental problems are usually caused by the flows/release of certain substances. Therefore, there is a direct link between the size of the substance flow and its (potential) environmental impact. Such a link cannot be established for physical flows on higher aggregation levels. Material as well as aggregate flows can only be linked to environmental impacts by linking them to the substance releases causing the problem. Hence, to prioritise MFA policies in a strategic policy approach physical flows need to be addressed on the various aggregation levels within one analytical framework. However, the links between bulk materials and substances are only well established for particular environmental problems such as global warming or acidification. The previously recommended review of IPAs therefore should also identify where these links between substance and bulk materials flows need to be strengthened in the future for moving towards a fully integrated material flow evidence base.

Figure 4 – MFA methodologies in an integrated material flow approach

In the main report a variety of examples of strategic MFA models are provided. These inform SCP policy in key areas such as the environmental performance of industrial sectors and companies (see 4.11.1), integrated product policies (see, 4.11.2) or sustainable waste management (see, 4.11.3).

2.3 Towards a methodology for Tracking Strategic Materials in the UK

The last Section of the main report responds to the Government’s request to **identify strategic materials and to propose a methodological framework for tracing them**. This Section provides suggestions on which materials might be of particular interest for a strategic resource management approach using existing evidence. It can be seen as one particular component of the approach proposed in section 2.2.

1. Identifying key materials based on environmental impacts

A material is proposed to be of strategic importance⁸ for the development of more sustainable resource use patterns in the UK, if

- **the material has a particular high impact for a key environmental theme on the UK’s SCP/ environmental agenda.** Key themes can only be identified by the Government. In this case the study focuses on **climate change**, already identified by the government as “the greatest (environmental) threat” (DEFRA, 2005:72).
- **the material has a relatively high impact in most impact categories.** Results from a study by Van der Voet et al. (2005⁹) for the UK are taken to analyse the environmental impact of 31 (finished) materials¹⁰ in 13 impact categories in the light of the Government’s SCP and SD agendas. By looking at climate change together with the 12 other impact categories the shortlist¹¹ shown in Table 1 was generated.

Table 1 – Shortlist of strategic materials

Shortlist of Materials of strategic environmental importance
Aluminium
Iron and Steel
Paper and Board
Plastics
Animal Fats

⁸ It should be noted that this prioritisation process does not take other economic and social issues into considerations. This would ideally be the case for SD and SCP policies.

⁹ The study by van der Voet et al. (2005) used to identify five key materials is the most comprehensive attempt to link material flows with environmental impacts across a wide range of impact categories.. However the approach also has its limitations which are described in the main report.

¹⁰ It is important to note that the 31 material groups under consideration are neither raw materials nor products, but finished materials. Finished materials are “materials just one step away from being applied in a product. Wheat and cotton are then materials, not bread or textile. Glass is the material, not windows or bottles, nor sand [...]” (Van der Voet et al., 2005:34)

¹¹ In this case natural gas, hard coal, and oil are not selected because they are already traced on a regular basis through large databases such as the Environment Accounts. Even though copper, nickel and zinc rank high on a per unit flow level they are not selected because their aggregate impacts tend to be below average in the various impact categories.

The materials in this shortlist could be considered of strategic importance for achieving more sustainable patterns of resource use but can only be seen as a first suggestion due to quality concerns associated with the study of Van der Voet et al. (2005). **The government should consider commissioning a study which identifies strategic materials based on the best available data for the UK.**

2. Towards a modelling framework for tracing strategic materials

To trace the key flows of strategic materials through the economy a hybrid methodology is proposed which combines bottom-up and top-down data

In a *first* step bottom-up data could be compiled and presented as conventionally done in Bulk Material or Material System Studies. This bottom-up data could be the starting point for a *second* stage of analysis where the physical data would be framed into a hybrid input-output model. In this context industrial sectors would be further broken down according to product demands. This would be achieved through the combined use of available monetary and physical data as well as statistical optimisation methods. This additional analytical stage provides an array of new opportunities for dealing with material flows through policy interventions from material prevention to material substitution and recycling.

For three of the five proposed materials the data is available at the required levels. The same is true for plastics as long as aggregate plastic flows are concerned. For a more disaggregated treatment of plastics the availability of monetary and physical data would need to be further explored. The same is also true for animal fats, which would require a more disaggregated treatment of some supply chain flows. Therefore, it is recommended that a framework for two or three unproblematic materials is developed first. In later stages materials with more complex supply-chains could be added. Further considerations in relation to all the materials highlighted here discussed in depth in the full version of this study.

2.4 Summary of recommendations

A full list of recommendations is provided in the full length version of this study. The wider strategic recommendations can be summarised as follows:

- The government should aim to **implement a strategic material flow approach** to inform SCP policy, which focuses on materials with the most detrimental environmental impacts first. This would encourage the most effective use of existing MFA evidence and build-up of new MFA evidence base. Such an approach aims to minimise the life cycle impacts of materials through dematerialisation including reuse/recycling as well as detoxification (material substitution). A general framework for prioritising material flows according to their environmental impacts and where physical evidence is required in this process has been proposed.
- In order to prioritise material flows, **MFA methodologies need to be linked with (potential) environmental impacts** as commonly done in the LCA literature.
- **A comprehensive model should be built-up to inform these prioritisation processes.** Two complementary approaches that can achieve this are outlined in the full length version of this study.

3 Review of Biffaward Studies

(by Robin Vanner and Paul Ekins)

The Biffaward series of reports were commissioned following the publication in 1997 of an overview publication (Biffa 1997) relating to resource use and waste management in the UK. The rationale for the investment of more than £10.6 million from the landfill tax credit scheme was that information about resource flows through the UK economy is of fundamental importance to the cost effective management of those flows, especially at the point at which those flows become ‘wastes’. With the Biffaward programme of research nearing completion, this assessment identifies those studies which are both sufficiently robust and relevant to future policy agendas. The results of the assessment have been the subject of a formal consultation with the reports’ authors, as well as a dialogue with practitioners and policy makers through a project workshop. Table 2 shows how the studies relate to the chain of production and consumption. Of the 48 studies which have been assessed:

- 7 studies can be used to inform policy directly (see table 3).
- 29 studies can be used to inform policy, but with a note of caution about some aspect of the study (in many cases this is due to the results representing modelled data’ (see table 4)
- 12 studies were assessed not to be usable in relation to future policy without further work. (see table 5)

Production				Products	Consumption			Waste			
Primary production studies				Product studies	Regional studies			Waste studies			
Mining	Poultry	Pigs			Scotland	South west	South east	Data flow	Furniture wood		
Secondary production studies					Auto	NI	Isle of Wight	REMAT	Furniture packaging		
Chemicals	Construction	Paper	Ceramics		Houses	Wales	London		Furniture solvent		
Glass	Foundry	Iron & steel	Power		Newspapers	Eco-Budget UK			Packaging	Timber	
Tertiary (service) sector studies					Clothes				Glass tube lamps		
Health		Public	Education		Tyres	Tourism			Scottish waste transport		
Schools	Finance	Exhibition							Agricultural waste (MB)		
									Civic sites	EuroCharge	WEEE
									Agricultural waste strategy)		
								Thermal methods			
Material studies											
Methane											
Carbon											
Wood											
Nitrogen											

Table 2 – The robustness of the evidence base provided by the Biffaward studies

Code	Title	Score
-	Methane	32
B/1783	Waste Data Flow	32
B/1425	Producer responsibility (REMAT)	31
B/1635	National Health Service - Material Health	28
B/1355	Carbon UK	28
B/1352	Tyres	26
B/1597	Agricultural Waste (Mass balance)	23

Table 3 – Studies which can be used directly to inform policy

Code	Title	Score	Limitation of study
B/1831	Scotland	32	Modelled data
B/2230	Ecological Budget UK	32	Modelled data
B/1996	South West - Stepping Forward	31	Modelled data
B/1946	Northern Ireland - Northern Limits	30	Modelled data
B/1646	London - City Limits	27	Modelled data
B/1716	Transport Options for Scottish Waste	27	Age of Data
B/2011	Wales	27	Modelled data
B/1699	South East - Taking Stock	26	Modelled data
B/1837	Newspapers UK	26	Modelled data
B/1663	Automotive	26	Non-direct flows
B/1705	Iron, Steel and Aluminium (Economic)	26	Non-direct flows
B/1698	Iron, Steel and Aluminium (MFA)	26	Non-direct flows
B/1601	Chemicals	25	Non-direct flows
B/1445	Nitrogen UK	25	Age of data
B/1406	Construction	25	Age of Data
B/1640	Housing	24	Not updateable
B/2043	Electricity Generation	24	Non-direct flows
B/1776	Magazine Publishing	24	Incomplete coverage
B/1303	Isle of Wight - Island State	24	Modelled data
B/1850	EuroCharge	23	Not updateable
B/1412	Paper and Board Industry	23	Not updateable
B/31	Waste from electrical and electronic equipment	23	Age and level of modelling of data
B/2182	Food and Drink Processing	23	Non-direct flows
B/1413	Civic Amenity Sites	22	Not updateable
B/2173	Wood	22	Incomplete coverage
B/1505	Ceramics	20	Not updateable& modelled
B/1265	Agricultural Waste (Strategy)	20	Age of data and not updateable
B/1826	Thermal Methods of Waste Treatment	16	Data & compatibility
B/1584	Foundry	15	Age of data, not updateable, modelled and only direct flows

Table 4 – Studies which can be used for policy with an appreciation of the study's limitations

Code	Title	Score
B/1634	Exhibition Industry	19
B/1489	Glass Manufacture in UK	18
B/1524	Public Sector	17
B/2068	Education	16
B/1224	Schools	16
B/1410	Furniture Packaging	18
B/1127	4Sight Rocks to Rubble	14
B/1424	Solvent Waste in Furniture Manufacturing	13
B/1815	Wood combustion in furniture manufacturing	13
B/1536	Financial Sector	13
B/1448	Glass from Fluorescent Tubes and Lamps	12
B/1411	Timber Waste	-

Table 5 – Studies which should not be used to inform policy without further work

4 Development of an Indicator for Emissions and Impacts associated with the Consumption of Imported Goods and Services (By Thomas Wiedmann, Jan Minx and John Barrett)

Findings and conclusions from the literature review

When people in the UK consume goods or services they also produce carbon dioxide emissions, not only directly, for example when driving a car, but also indirectly. This is because the production of these goods or services will, most likely, have involved the emission of carbon dioxide earlier on. These indirect “emissions from consumption” can occur anywhere, even in foreign countries when goods or services are imported to the UK. In a manner of speaking, these emissions are “embedded” with the consumption activity.

There are a number of good reasons why national Governments should report environmental (and other) impacts embedded in trade, e.g. to improve sustainability reporting indicators, to enable meaningful international comparisons, to instigate country dialogues and assist in trade negotiations or to generally raise awareness amongst consumers.

It is difficult, though, to measure these embedded emissions. At present, there is no standardised calculation method and therefore no reliable indicator that quantifies total “emissions from consumption” is currently available.

This project set out to identify the most appropriate approach for constructing such an indicator and an extensive literature review was undertaken. The assessment of the findings was aimed at identifying the strengths, weaknesses, assumptions, limitations, data requirements and suitability of different approaches.

Many studies assume that all imports are produced using UK production technologies. This is called a ‘single-region’ assumption. However, foreign countries use different production technologies and energy mixes and therefore the results are not very helpful. A sound response to this problem is to extend the basic single-region framework to the international case and to employ a multi-region model, ideally covering all trading partners of the country under investigation. In addition, the review showed that such a model should also use input-output analysis, a well established method that automatically takes into account the impacts of all steps that were required to produce the goods and services that are consumed.

For these reasons, a ‘multi-region input-output’ (short: MRIO) approach seems to be the most suitable and promising choice for a model that calculates an embedded emissions indicator. A specification for the development of a MRIO indicator for embedded emissions is given in the report and options for the actual implementation, including cost reduction options, are presented.

The implementation and application of a full MRIO framework poses three basic challenges: data availability, data reconciliation and computability. These issues and possible practical solutions are discussed in detail in the report. The crucial part of an operational MRIO framework is a code protocol that processes data of any kind in a highly efficient way. In essence, this is a sophisticated computer programme that can ‘digest’ data from different countries and years in different classifications and valuations with data gaps and inconsistencies.

We describe numerous policy and other applications of the specified approach. Most importantly, the suggested model allows for a robust, reliable and reproducible quantification and analysis of environmental impacts embedded in the international trade of goods and services – not only carbon dioxide emissions, but ultimately all sorts of environmental and social impacts. This is a novel

approach. Studies so far either covered trade only partially or used short-cut estimates that do not really withstand scientific scrutiny and that cannot be truly relied upon in international negotiations about (embedded) emissions.

Recommendations for the practical implementation of an indicator model

The crucial part of an operational MRIO framework is a code protocol that processes data of any kind in a highly efficient way. In essence, this is a sophisticated computer programme that can ‘digest’ data from different countries and years in different classifications and valuations with data gaps and inconsistencies. Furthermore, the programme allows a flexible breakdown of economic sectors if this is required to answer specific questions. An efficient data handling protocol of this type helps reduce cost and time requirements while at the same time allowing a consistent update of the model.

Realising and operating a complete MRIO model is a major undertaking and requires both careful planning and joint efforts. As the resource requirements are substantial, it is sensible to include cut-down options, to split up working tasks, and/or to build up the model in stages. The main advantage of the proposed model is its flexibility towards the integration of more data of any kind as well as towards a change in the policy, or research question the model is supposed to answer.

The objective of any future research should therefore be to implement an initial, relatively small, data and model framework that is easily expandable without major adaptations. Reductions in data and therefore resource requirements can be made by cutting down the number of countries/regions, years, sectors or indicators. A ‘slim’ option, for example, could initially feature just two regions (e.g. UK and the rest of the world) and be expanded over time. The relatively low data requirements of a two-region model allow the early construction of a time series of embedded emissions.

Recommendations for general future research in the area

The need for comprehensive and robust modelling approaches for embedded impacts in an international context using the MRIO framework has been recognised by research groups worldwide¹² and it can be expected that concrete proposals will be brought forward in the near future. The review conducted in this project clearly shows that an environmental MRIO model requires substantial efforts which can only be mustered if both funding bodies and research institutions pool their resources and expertise. Given the international context of the subject and existing research efforts worldwide it seems reasonable to seek international collaboration.

Several international bodies already hold large amounts of the data required for a MRIO model (e.g. GTAP, OECD and Eurostat for IO and trade data). One of these agencies or a consortium could maintain a MRIO database that also holds environmental accounts data. Developing, harmonising and standardising these data bases would be of general benefit, not only for MRIO modelling but for countless other research and policy applications as well.

With respect to impacts other than CO₂ emissions, further general research is required to consolidate existing data sets and modelling approaches. Numerous studies have proven that input-output modelling is appropriate to analyse these other indirect (embedded) impacts (water, waste, materials, etc.), but consistent data accounts are still the main obstacle for implementation. If environmental accounts were systematically extended with detailed accounts of water use, waste generation and disposal, recycling, land use etc., ideally in an internationally harmonised system, a boost in scientific and practical applications could be expected.

¹² See full report for references.