2 Assessing the Material Consumption of the South East Region

2.1 Introduction

An overview of the methodologies employed in the study has been given below. Details of individual components are given in more depth in the following chapters. This chapter acts as a basic description and summary of the approaches of material flow analysis and the ecological footprint.

2.2 Material Flow Analysis

2.2.1 Mass Balance Framework

The Mass Balance projects have an obligation to the "Mass Balance Framework" that has been devised by Forum for the Future[1]. The Forum approach is organised by Combined Nomenclature (CN) coding, which is a scheme used to track imports and exports, primarily for excise purposes, but it provides a ready-made classification that is widely used in industry.

2.2.2 The use of PRODCOM within the Material Flow Analysis

The methodology described below explains how material consumption and production is devised. A considerable amount of the work involves the conversion of various different classification systems. The main database that is employed is PRODCOM (classified by the Standard Industrial Classification, SIC). The PRODCOM annual reports (PRA) contain data on UK sales, imports and exports in both value and volume measure[2]. From this, data concerning the actual consumption of each material/product can be derived. The term PRODCOM is derived from PRODucts of the European COMmunity. This is a survey based on products whose definitions are standardised across the EC to allow comparability between the member countries' data. Figure 2.1 indicates how these products are classified. PRODCOM covers some 4,800 products that in the UK are assigned to some 250 industries (subclasses) as defined by the 1992 Standard Industrial Classification SIC(92) and is available from the Office for National Statistics.

The Standard Industrial Classification is used to classify business establishments and other statistical units by the type of economic activity in which they are engaged. The present 1992 revision is based on the activity classification issued by the Statistical Office of the European Communities (Eurostat), known as the NACE classification.

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1 See http://www.massbalance.org/

2 PRODucts of the European COMmunity (PRODCOM), PRODCOM Annual Industry Reports 2000, Office for National Statistics, http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=9660&Pos=1&ColRank=1&Rank=256

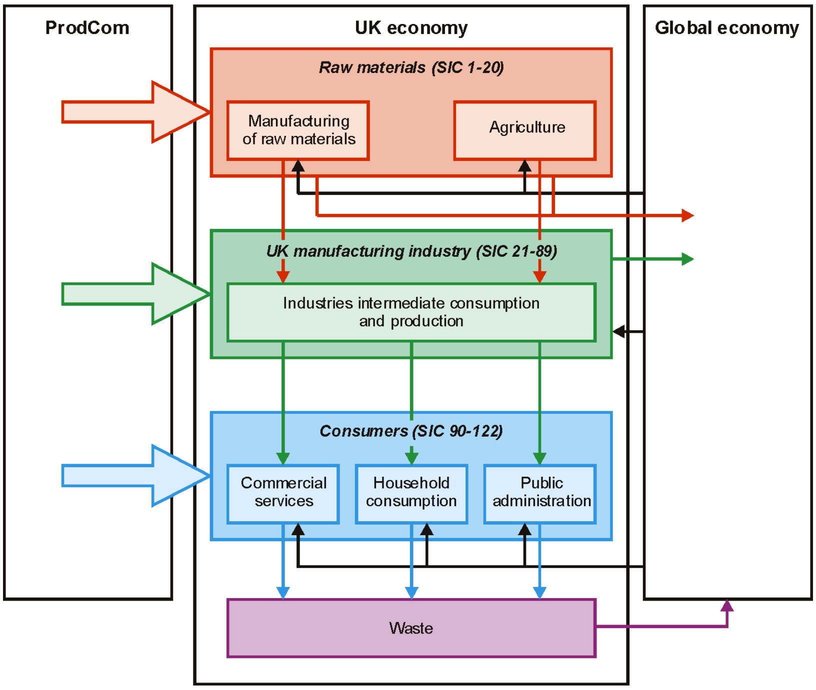

Figure 2.1 The use of PRODCOM in determining material flows in the UK

Items within PRODCOM can be divided into three main categories (raw materials, industries' intermediate consumption and final consumer products). To add all these three items together would be double-counting as the raw materials will be used to make the final products. Therefore, the tonnage of materials from the consumers and manufacturing sections should add up to the raw materials, taking into account exports and imports at each stage. In essence, the project will be constructing a simple "physical input-output table" for the UK (with an allocation to Wales and the regions later on). This means that not all the interactions between industries will be understood in the same way as the economic input-output tables for the UK, but there will be an understanding, by industrial classification of the tonnage of items produced for consumers (albeit via services) and the tonnage of materials required to produce these items.

With regard to household consumption the data will be organised by consumer items that appear within the economy using the classification system of the "Family Spending Survey". This list of items represents a coherent list that individuals will understand. It will include electrical and electronic equipment[3], household furnishing [4], clothes, nappies, batteries etc. Detailed patterns of consumer spending will be analysed and applied to the calculations. The material composition of all the items will be considered allowing the research to double-check the materials classified as raw materials by PRODCOM.

This basis of the analysis is built from the "Household Expenditure Survey" (HES). This employs the COICOP (Common Indexing Protocol Classification Of Individual Consumption by Purpose)

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3 Further information taken from the ICER (2000*) UK Status Report on Waste from Electrical and Electronic Equipment*, ICER, and Cooper T. & Mayers K (2003) *Prospects for Household Appliances*, E-SCOPE.

4 Further information taken from the European Association of Furniture Manufacturing.

classification system (4-digit). As well as being used for "Household Final Consumption Expenditure", as published in Consumer Trends, COICOP is also used for household budget surveys, as adopted for the UK Expenditure & Food Survey, and international comparisons of Gross Domestic Product.

All the trade data vital to the approach has been purchased from Customs and Excise. The data is classified in SITC (Standard International Trade Classification). This provides a detailed breakdown by tonnage of thousands of items. Software programmes have been developed to convert all items into the CN classification. In addition to ONS data, UK consumption data of key products were taken from industry reports. For example, The Paper Federation of Great Britain produce a comprehensive publication entitled "Reference Statistics". This provides valuable data of UK consumption of paper and paper products and fills many of the gaps that exist within PRODCOM.

2.2.3 Allocation of resource consumption to the UK regions

Two items of importance have not been considered within the approach described above. Firstly, the allocation of these consumer items to the UK regions and an assessment of transport distances. Details of the allocation of various resource consumption types are given below. The project relies on a vast database of survey data that provides a regional breakdown of consumption. Examples taken from some of the key components are given below with footnotes on other references employed.

Food

The total consumption of over 50 food types will be considered. This is based on the "National Food Survey" which provides a detailed regional breakdown. The energy required to grow, harvest and process the food will be taken into account (i.e. the embodied energy). The embodied energy of food packaging as well as the energy used to transport the food from where it was produced to the retail outlet will also be calculated.

Passenger transport

For petrol cars/vans, diesel cars/vans, buses, coaches, light and heavy goods vehicles and motorcycles, average emissions of CO_2, CH_4 and N_2O as well as fuel consumption per vehicle kilometre were derived from the National Atmospheric Emission Inventory (NAEI) Emission Factor Database (EFD). This database provides emission factors (per km) for a range of different pollutants, vehicles and types of roads used by the vehicle. It was decided to use this database as it is recognised by the UK Department for Transport (DfT) and local authorities as the most comprehensive collection of emission factors. The average emission factors for different types of roads (urban, rural single and dual carriageway and motorway) were calculated. CO_2 emissions of trains and aeroplanes (short and long distances) were adopted from DEFRA[5] while their specific emissions of CH_4 and N_2O and fuel consumption were derived from the NAEI-EFD.

Regional and local data on travel patterns (passenger kilometres travelled by mode and purpose) can then be used to calculate the material flow (and ecological footprint) associated with passenger transport.

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[5] http://www.defra.gov.uk/environment/envrp/gas/10.htm

Aggregates

This study follows the methodology of mass balance analysis in the 'Construction Industry Mass Balance' report produced by CIRIA and Viridis within the Biffaward Programme on Sustainable Resource Use (Smith et al. 2002[6]). In order to explore the environmental impacts of constructional and building activities an analysis of the regional consumption of aggregates and construction materials will be performed. The material flow analysis (MFA) comprises the following categories:

- amount of primary aggregates consumed;
- hidden flows of materials associated with the extraction and production of aggregates;
- amount of construction materials and products consumed;
- embodied energy of all aggregates, materials and products (as energy carriers equivalents);
- energy for transport (as energy carriers equivalents);
- greenhouse gas emissions associated with energy use; and
- waste produced within the construction sector.

Original data about material consumption in the construction industry will be used where possible. This will be the case for most of the data on aggregates as it can be taken from the British Geological Survey (2001) *Collation of the Results of the 2001 Aggregate Minerals Survey for England and Wales*. All other data will be calculated by using PRODCOM.

Freight transport

The freight transport component is very important when constructing scenarios on local sourcing. It is too complex to establish the origin and supply chain of every single product entering a given region and its sub-regions. Therefore, the following approach will be applied. The material flow will be established for five different freight transport distances and for five different transport modes. These are:

	Worldwide	***Europe***	***UK***	***Regional***	***Local***
Road	*[tonne-kilometres]*	…			
Rail	…	…			
Water (ship)					
Air					
Bicycle					

2.2.4 Coping with data gaps

Coping with data gaps is one of the major tasks within each MFA study. There can be a lack of:

- local/regional data;

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[6] Smith RA, Kersey JR, Griffith PJ (2002) The Construction Industry Mass Balance: resource use, wastes and emissions; *Viridis Report* VR4; CIRIA and Viridis

- national data; or
- data on proxies used to allocate national data to the regional level.

As mentioned earlier, consumption data from specific regional reports will be used whenever possible to overcome some of the data gaps.

2.2.5 Assessing the material production of UK regions

Production figures for the whole UK are available from the PRODCOM statistics 2000[7]. This is supported by the United Nations Statistical publication “Industrial Commodity Statistics”. According to Figure 2.2 “Sales” numbers in PRODCOM are regarded as domestic production. A part of this production is exported to countries outside the UK. The other part is produced for and consumed by the domestic market. Together with the imports this is the apparent consumption, stated as “Net Supply” in the PRODCOM list.

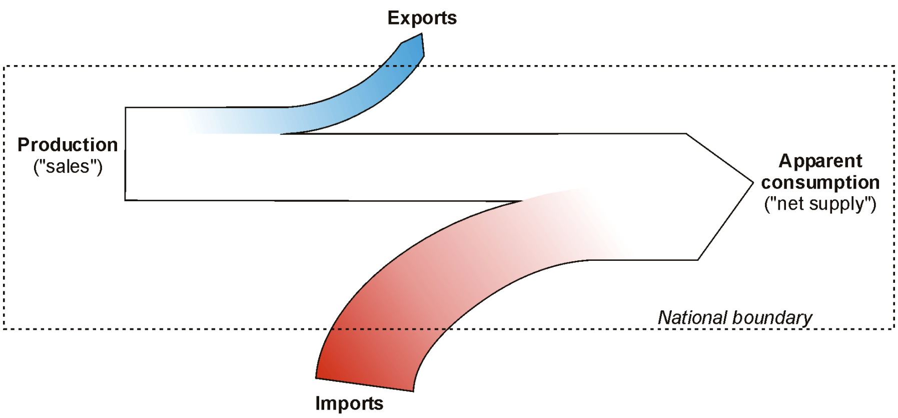

Figure 2.2 Definitions of terms used in the PRODCOM statistic.

For each of the SIC 8-digit categories all volume units other than ‘tonne’, such as for example, ‘litre’, ‘item’, ‘pair’, ‘m^2’, ‘km’, etc. have to be converted into ‘tonne’ by estimating average weights of all items within that category. This is possible for all categories within the SIC codes 14 to 29. It might be impossible however, for the SIC codes 30 to 36 as these codes contain machinery, transport equipment and furniture – items for which it is difficult to obtain average weights.

Some of the data within the PRODCOM list may not be available or may be suppressed for reasons of confidentiality. In a few cases there is data on monetary values of “Sales” (in £) and sometimes it is possible to use the average price for “Net Supply” to calculate a substitute number for volume (in tonnes), assuming the same price for production and consumption.

To establish the tonnage of materials produced in a particular location is notoriously difficult. The method that will be employed in this project is based on two approaches. Firstly, local data will come

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[7] PRODucts of the European COMmunity (PRODCOM), PRODCOM Annual Industry Reports 2000, Office for National Statistics, http://www.statistics.gov.uk/StatBase/Product.asp?vlnk=9660&Pos=1&ColRank=1&Rank=256

from specific industries located within the region. For example, there may be a large aluminium factory or steel works. Contact will be need to be made with these companies directly or with the relevant industry associations.

The second approach will both verify the collected data and fill in gaps. A proxy will be developed based on employment. National data is available concerning production by SIC 2-digit code along with information concerning the number of individuals employed within these industrial sectors. With local information on employment the national figure can be scaled down to the local level.

2.2.6 Assessing the energy flows of UK regions

To calculate the embodied energy of materials and manufactured products, energy carrier conversion factors will be derived for each industrial sector by assuming the fuel/energy mix given in the International Energy Agency (IEA) energy statistics and balances for 1999 (the latest year for which the data is available). Where electrical energy formed part of the mix, this will be converted into energy carriers and added to the tonnages of fuel before calculating the direct and hidden flow conversion factors. As examples, the derivation of the energy carrier conversion factors for the iron and steel industry are shown in Table 2.

Similar conversion factors will be calculated for the following industrial sectors: non-ferrous metals (e.g. aluminium), chemicals (including plastics), non-metallic minerals (including glass), machinery (including electrical appliances), mining and quarrying, food and tobacco, wood and wood products, construction, textiles and leather, and 'other industry' (e.g. rubber, batteries).

Table 2.2.1 Derivation of energy carrier conversion factors for the iron/steel industry.

Iron and steel industry	All coal	Hard coal	Brown coal/lignite	Peat	Petroleum products	Natural gas	Solid biomass (wood)	Electricity	Total
Consumption (PJ)	683				66	378	0	366	1493
Direct consumption (kt)		37669	0	0	1618	9418	1.5		48706
Consumption via electricity (kt)		6571	8648	177	1260	2099	106		18861
Total consumption (kt)		44239	8648	177	2878	11517	108		67567
Conversion factors - energy carriers (t/GJ)		0.0296	0.0058	0.0001	0.0019	0.0077	0.0001		**0.04527**
Hidden flows (kt)		171206	76967	44	0	0	0		248218
Conversion factors - hidden flow for energy carriers (t/GJ)		0.1147	0.0516	0.0000	0.0000	0.0000	0.0000		**0.16630**

Without energy analysis the MFA would provide little meaning with regard to the impact of the different materials entering the economy. The inclusion of energy in the MFA can also be used for the development of sustainability indicators. For example, MFA can be seen as an instrument for aggregating various environmental impacts into a few strategic indicators such as the total throughput of materials, energy intensity per unit or even the decoupling of material and energy use from economic growth. In some cases the material composition of a particular product will need to be known before it is possible to understand the energy carriers associated with this product.

2.2.7 Assessing the hidden flows of UK regions

Not only must the final commodity be seen as a material input but also the energy required to produce the product (hidden energy carriers) and the hidden flows (secondary) of the resource extraction have to be taken into account. The 'hidden flow' is the portion of the total material requirements that never enter the economy. Hidden flows occur at the extraction or harvesting stage, for example, when coal is being mined or forests are being cut down. The hidden material flow comprises two components: ancillary flows and excavated and/or disturbed flows. Although these two components can have markedly different environmental impacts, for the purposes of physical accounting – in system terminology – hidden flows represent a simultaneous input and output. Ancillary material flow is the material that must be removed from the natural environment in order to obtain the desired material. Examples of ancillary material flows include:

- the portion of an ore that is processed and discarded to concentrate the ore; or
- the plant and forest biomass that is removed from the land along with the logs and grain but is later separated from the desired material before further processing.

Excavated and/or disturbed material flows are materials that are moved or disturbed to obtain a natural resource or to create and maintain infrastructure. Disturbed material flows include:

- the natural materials that must be removed to permit access to an ore body;
- the soil erosion from agriculture; and
- the material moved in the construction of infrastructure such as a highway or building or in the dredging of harbours and canals.

Each item of material consumption has an associated hidden flow. Within this study, the hidden flow of most items will be considered.

2.2.8 Assessing the waste flows of UK regions

Waste flows are defined as the quantity (weight) of materials that are dispersed into the environment as a deliberate or unavoidable consequence of product. Waste from private households, industry and commerce and wastewater management activities (sewage sludge) will all be included in the calculations.

Material outputs also comprise gaseous air emissions and solid and liquid waste flows. The project will consider the emissions to air of three major greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as well as a range of other health related pollutants. The air pollutants will be divided into two main categories: emissions from production and emissions from consumption.

We intend to provide a more detailed overview of the waste and materials management sector. This is the sector most concerned with movements of material as such, but also where policy choices revolve around impacts on transport, emissions, and land use. The issues in waste disposal, recycling and minimisation are complex, and therefore the aim of this module is simply to relate the key problems and opportunities in waste management to the overall regional mass balance / footprint. This involves a detailed analysis associating the inputs to the economy and the outputs.

The project will be extended to consider (in outline):

- other major waste streams such as material streams including paper/board, food/organics, metals and glass;
- major waste-producing industries; and
- particular impacts of waste management, such as land-use or transport.

2.2.9 Addressing double counting

When accounting for the consumption of material and related emissions it needs to be made sure that no double counting occurs, i.e. that for example intermediates, transport or packaging are counted twice. The approach employed here tries to minimise double counting while at the same time providing a complete picture of consumption. The following table lines out where double counting issues occur and how they have been addressed. A detailed description of all accounts is given in Chapter 3.

Table 2.2.2(a) Addressing double counting in the MFA/EF approach

0: Food & Agriculture		1: Energy & Water		3: Man. Durables		
Food & Drink, Households	**Food & Drink, Restaurants**	**Households**	**Commercial Sector**	**HH Cars**	**HH Furniture, Floor Cov.**	**HH Electrical Equipm.[a)]**
Transportation and packaging worked out separately → Chapter 3.4	Transportation and packaging worked out separately → Chapter 3.4	no double counting issue	no double counting issue	CO_2 emissions & EF of manufact. & maintenance of cars are included in the Passenger Transport category (7: Transport Services)	no double counting issue	no double counting issue
Transportation and packaging included in the final EF number	Transportation and packaging included in the final EF number					

a) MFA of electrical equipment has been worked out separately (see Chapter 3.7) but has not been included in the final EF number.

Table 2.2.2(b) Addressing double counting in the MFA/EF approach

4: Man. Consum.	5:Construc. Services	6:Consumer Services	7:Transport Services		9: Public Services	Built Land	Waste
HH Consu-mables	**Construction Materials**	**Commercial Services**	**Passenger Transport**	**Freight Transport**	**Public Admin.**		
Packaging worked out separately → Chapter 3.6	Intermediates subtracted; transportation worked out separately → Chapter 3.5	Car use for business purposes included in passenger transport	EF Includes CO_2 emissions of manufacture and maintenance of cars	Includes all Freight Transport relevant to the SE	Car use for public admin. purposes included in passenger transport	Road space is allocated to cars in the passenger transport component	EF of waste is seen as 'satellite account'
Packaging included in the final EF number	Intermediates not included; transportation included in the final EF number		EF includes (non-transport related) built land area			All other built land is included in this section	Not included in the final EF

2.3 The Ecological Footprint

2.3.1 Background

The ecological footprint (EF) provides an aggregated indicator of natural resource consumption (energy and materials) in much the same way that economic indicators (such as Gross Domestic Product or the Retail Prices Index) have been adopted as a way of representing dimensions of the financial economy.

Co-originated in the early 90s by Professor William Rees and Dr. Mathis Wackernagel, ecological footprint analysis has rapidly taken hold and is now in common use in many countries at national and local levels. Its application includes analysis of policy, benchmarking performance, education and awareness raising and scenario development. The European Commission's Common Indicators Programme (www.sustainable-cities.org) has adopted the EF as an indicator of regional environmental sustainability and the methodology has support from many in the public, private and civil sectors worldwide.

An annual *Footprint of Nations* study, now published as part of the *Living Planet Report* (WWF et al., 2002), provides a national context for considering regional ecological footprints (Lewan, L. & Simmons, C., 2001, and Chambers, N. et al., 2000). The methodology has become more refined providing a more accurate picture of human appropriation of nature each time.

There are numerous examples of ecological footprints projects. A short description of the methodology has been given below. However if you wish to explore the methodology of the ecological footprint in more depth then please refer to the following studies:

- World-Wide Fund for Nature International, United Nations Environment Programme, World Conservation Monitoring Centre, Redefining Progress & Center for Sustainability Studies (2002) *Living Planet Report 2002*. World-Wide Fund for Nature, Gland, Switzerland.
- Lewan, L. & Simmons, C. (2001). *The use of Ecological Footprint and Biocapacity Analyses as Sustainability Indicators for Sub-national Geographical Areas: A Recommended Way Forward.* http://www.prosus.uio.no/english/sus_dev/tools/oslows/2.htm
- Chambers, N., Simmons, C. & Wackernagel, M., (2000). *Sharing Nature's Interest: Ecological footprints as an indicator of sustainability*. Earthscan, London.
- Wackernagel, M., Schultz, N. B., Deumling, D., Callejas Linares, A., Jenkins, M., Kapos, V., Monfreda, C., Loh, J., Myers, N., Norgaard, R., Randers, J. (2002) PNAS 99(14) 9266-9271
- Aall, C., Norland, I. (2002). *The Ecological Footprint for the municipality of Oslo – results and suggestions for use of ecological footprint as a sustainability indicator.* (Det økologiske fotavtrykk for Oslo kommune – resultater og forslag til anvendelse av økologisk fotavtrykk som styringsindikator). Report. Western Norway Research Insitute/ProSus. (English summary can be downloaded from http://www.vestforsk.no/publikasjonar.asp?gruppe=Miljøgruppa)
- Simmons, C., Lewis, K. and Barrett, J. (2000) Two feet - Two Approaches: a component-based model of ecological footprinting. *Ecol Econ.* **32** pp375-380

- Barrett, J.; Vallack, H.; Jones, A. & Haq, G. (2002). *A Material Flow Analysis and Ecological Footprint of York: Technical Report.* Stockholm Environment Institute, Sweden.

2.3.2 What is an ecological footprint?

EF essentially accounts for the use of the planet's renewable resources. Non-renewable resources are accounted for only by their impact on, or use of, renewable, bioproductive capacity. The footprint deals only with demands placed on the environment. It does not attempt to include the social or economic dimensions of sustainability. The footprint is a 'snapshot' estimate of biocapacity demand and supply usually based on data from a single year. Both available biocapacity and the eco-efficiency of the economy can change over time which is why it is not possible to forecast or 'backcast' footprints from current data although it is possible to make assumptions about future consumption and thus create informative scenarios.

The use of bioproductive area as an aggregate unit makes it a powerful and resonant means of measuring and communicating environmental impact and sustainability. In this sense it is comparable to many economic indicators such as the Retail Prices Index (RPI) and GDP.

The EF of a region or community is defined as the bioproductive area (land and sea) that would be required to sustainably maintain current consumption, using prevailing technology. Probably the most important dimension of the ecological footprint is the fact that impact is related to the city or region that consumes the goods and services. Traditionally, environmental pressures were mostly local or national, meaning the consumer was affected by the environmental consequences of the production. However, now the geographic location of environmental pressures has little relation to the location of consumption. EF takes on the task of re-allocating the environmental pressures to the consumer.

To determine the final footprint figure the following equation can be applied:

$$EF = \sum_{i=1}^{i=n} (D + N)$$

Where *EF* = total ecological footprint; *D* = direct land use; *N* = additional land requirement[8]

i represents the number of component parts to the footprint.

It is not necessary to divide the final figure by the population.A per capita figure however does provide a useful tool for comparison with other countries, regions and local authority areas.

2.3.3 Measuring the EF

For the purposes of the ecological footprint calculation, land and sea area is divided into four basic types: bioproductive land (sub-divided into arable, pasture and forest), bioproductive sea, energy land

[8] The main part of additional land is notional "energy land" that is required to sequester carbon dioxide emissions from the use of fossil fuels (see below) or – alternatively – supply the energy through renewable biofuels.

(forested land and sea area required for the absorption of carbon emissions) and built land (buildings, roads etc.). A fifth type refers to the area of land and water that would need to be set aside to preserve biodiversity (see Figure 2.3).

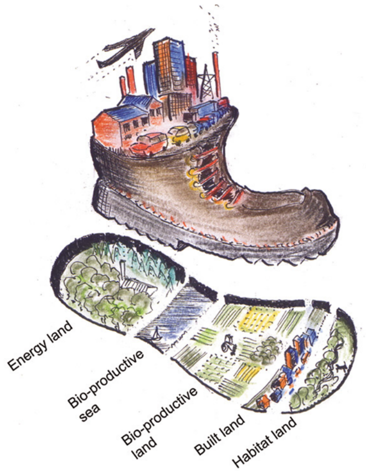

Figure 2.3 Summary of area types used for ecological footprint analysis (Source: CURE)

The footprint is measured in a standardised area unit equivalent to a world average productive hectare (abbreviated to global hectares or gha). This permits comparisons between countries and regions. This ‘demand’ can be compared with the productive area available biocapacity on the planet (the sustainable supply) to estimate the sustainability of current resource demand. Globally, the average personal ecological footprint was 2.3 gha in 1999 (the most recent year for which data has been calculated) – as opposed to an available capacity of 1.9 gha (excluding biodiversity considerations) – suggesting that humanity is using more natural resources than can be sustained in the long term (WWF et al., 2002, Wackernagel, M. et al., 2002, Wackernagel, M. et al., 1999).

The ecological footprint is defined as consumption (kg) times production efficiency (hectares/kg). Production efficiency in EF terms means simply how much bioproductive area it takes to produce one unit service of a given product. The EF depends on the efficiency of production – for a given farmer/county/state/country, their footprint varies depending on whether they use more land or less land to produce a given unit of goods or services. For example, in terms of direct energy use, the EF calculation is as follows:

$$\mathrm{EF} = a \times b \times c$$

Where a: Population

b: Average energy use per household (GWh)

c: The impact of producing a GWh of energy

The ecological footprint confirms Ehrlich and Holdren's definition of human impact on the environment. This being (Ehrlich P. & Holdren J., 1971):

$$I = PAT$$

Where: I is impact, P is population, A is affluence, and T is technology.

In the Ehrlich-Holdren formulation the impact (I) corresponds to a population's ecological footprint and is a function of population size and consumption (converted into a land area). Consumption is a function of affluence (A) and the state of technology, therefore presenting a "land-based analogue" of PAT (Rees, 2000).

Notional Carbon Ecological Footprint

The value in considering carbon dioxide emissions in terms of "sequestration" land is that it provides a visual depiction of these atmospheric emissions. This clearly demonstrates the current unsustainable patterns of Western societies who, in all cases, require an unacceptably large amount of land to provide them with their goods and services and sequester the subsequent CO_2 emissions. The carbon footprint is an accounting method. There is no suggestion that carbon sequestration is a more valid approach than reducing CO_2 emissions. Moreover, the carbon land component demonstrates that a "Sequestration Policy" is not possible as the current population would require a greater amount of land than is available on the earth.

Figure 2.4 below demonstrates the global carbon cycle. It is clear that the use of fossil fuels is responsible for an accumulation of carbon in the atmosphere. In a sustainable situation there would be no such build-up of greenhouse gases (this assumption is embedded within the ecological footprint concept). The EF considers the amount of extra forest land that would be needed to remove this accumulation. Moreover, it considers who is responsible for atmospheric accumulation of carbon through consumption. However, there is more than one method to assess the land area required to remove carbon accumulation in the atmosphere. These are considered below along with the carbon sequestration approach.

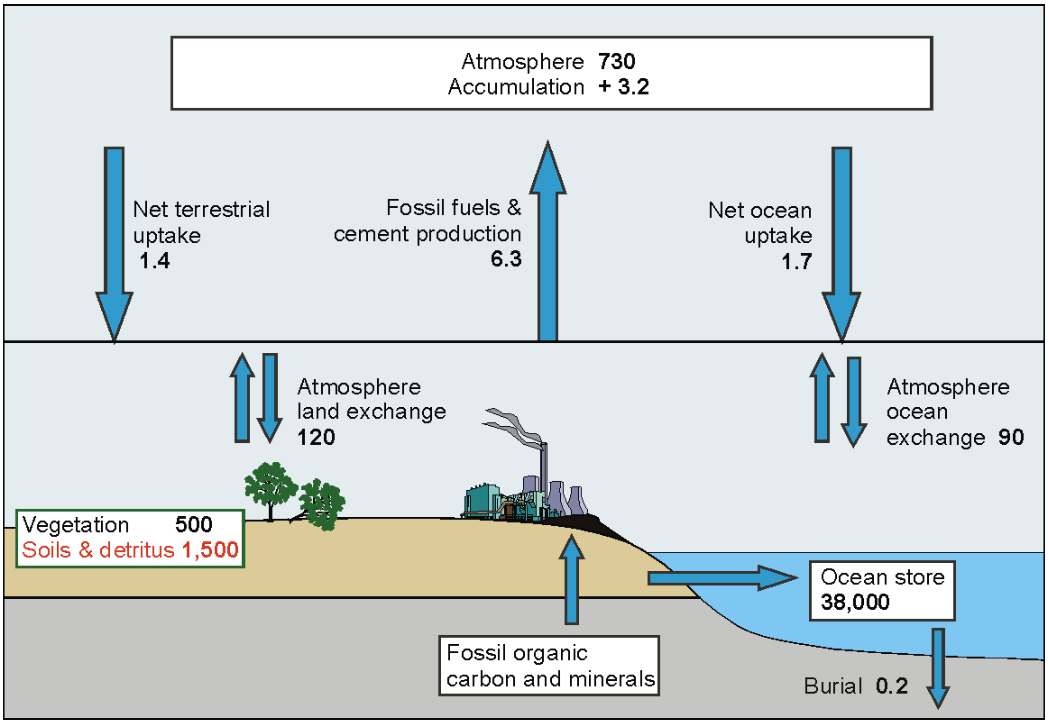

Figure 2.4 *Global carbon cycle (stores in PgC; fluxes in PgC/yr) (adapted from IPCC (2001) Climate Change 2001. The Scientific Basis. Cambridge University Press)*

The rate at which forest land can sequester carbon dioxide is debatable. The approach employed by Wackernagel is calculated by estimating the weighted average across 26 main forest biomes. This equates to a sequestration rate of 5.2 tonnes CO_2 per ha. Van Vuuren et al (1999) cite other publications that have derived vastly different sequestration rates. Of these publications, Nabuurs et al (1999) suggest different sequestration rates between various countries of between 2.2 to over 10 tonnes CO_2 per ha. These vast differences are of concern when the "notional" land of carbon footprints is combined with the "real" land components. The conversion factor employed for CO_2 to forest land could have a huge effect on the final land value. Therefore, it is important to be careful when combining various elements of EF. The ecological footprint can be seen as a land use calculation of a Greenhouse Gas Emission calculation.

An alternative method is to consider the amount of land required to produce biomass energy crops as a replacement for fossil fuels. Wackernagel and Rees' (1996) assumption is that it is preferable to use carbon that is cycling actively than to release carbon from a locked-up source. Ethanol is a fuel that can be seen as a biologically produced substitute for liquid fuel. The EF could represent the amount of land that is required to produce the equivalent amount of ethanol.

In this study, to support consistency between other studies, Wackernagel's calculation of 5.2 tonne CO_2 per ha will be applied. This allows comparability between different ecological footprint approaches.

2.3.4 Consistency across EF approaches

The basic ecological footprint is an additive model. It sums several mutually exclusive uses of bioproductive area: arable, forest (for both wood products and carbon sequestration), pasture, degraded or built land, and sea space. Exceptions to the additive model have been made for footprinting certain types of pollution and water catchment where spatial uses overlap.

A key issue in the calculation of ecological footprints and biocapacities is the method used to aggregate areas of different quality facilitating international comparisons. Areas of generally different productivity (arable, pasture, forest, sea) are 'normalised' by multiplying them by equivalence factors relating to their bioproductivity. The equivalent areas are then expressed as standardised hectares of world average productivity (more recently referred to merely as 'global hectares').

Use of fossil fuel-derived energy is typically accounted for in terms of its carbon dioxide emissions although it is also possible to assess ecological footprints of energy use in terms of the land area required to sustainably derive biofuel alternatives (as previously discussed). The former results in a more conservative estimate of the impact of fossil fuel use and has thus been the more common method.

The use of embodied energy is a debatable subject within the ecological footprint community. The "Living Planet Report" has used more conservative estimates for the embodied energy of products. The reality of the situation is that other embodied energy calculations suggest that the current ecological footprint could be approximately 30 per cent higher. The authors recognise the value of consistency and comparability with other ecological footprints and have therefore adopted the more conservative figures that are used more widely. At the same time, the authors recognise the importance of improving the methodology and providing a more accurate picture of human appropriation of nature.

2.3.5 Biocapacity

For calculation of national/regional biocapacity, local yield factors are introduced. These factors show how much more or less productive local areas are compared to the global average.

Some biocapacity must be set aside for non-human use. The necessary amount of pristine habitat is not known but, as a general rule in footprint calculations, not more than 88 per cent of the existing biocapacity is considered 'available' for human use. The Living Planet Report 2002 accounts for biodiversity as a percentage of the footprint (demand). Previously biodiversity area has been subtracted from the available regional supply.

2.3.6 Critiques of the Ecological Footprint concept

Several critiques of the ecological footprint exist (notably VROM-Council 1999, Van Kooten and Bulte, 2000, van den Bergh and Verbruggen, 1999, Pearce, 2000). These reviews contain a mix of positive and negative comments relating to the application of the methodology as well as suggestions for improving its structure and use.

Simmons and Lewan (2000) also listed suggestions for improvements arising from their analysis of seven European regional footprint studies and in consultation with a team of European footprint experts. It should be noted that since these papers were published, several notable improvements to the footprint methodology have indeed been made as part of the 2002 release of the Living Planet Report (Loh et al., 2002, Wackernagel et al., 2002a, Wackernagel et al., 2002b). However, it is nonetheless important to understand the limitations of the methodology, its strengths and weaknesses.

Here we paraphrase ten key points listed by Van Kooten and Bulte (2000) and use these as a framework for comment. Their comprehensive critique is arguably the most harsh of those listed above and was used by Pearce as the basis for his submission to the EU Commission DGXI. One of the co-founders of the ecological footprint concept, Dr. Mathis Wackernagel, has also had the opportunity to address the points raised in a corresponding submission to the EU Commission (Wackernagel, 2000) and here we draw on his comments augmenting these with our own thoughts and experiences. The reader is also referred to Chapter 6 of 'Sharing Nature's Interest' (Chambers et al., 2000) which addressed these and additional points. In an effort to address the criticisms of ecological footprints a number of them are listed below, each followed by a counter argument.

Footprint accounts are incomplete

Ecological Footprint Analysis does not claim to account for all human impacts on the environment. Instead it prefers to offer a conservative underestimate whilst acknowledging that other impacts exist. Most obviously, the accounts focus on resource consumption, with the exception of water, and underestimate the impacts of waste products.

However, several footprint studies have addressed both of these shortfalls. Chambers et al. (2000) demonstrate two methods of incorporating water consumption into footprint accounts. The same publication presents a study which includes footprint estimates for several pollutants.

Other studies have tackled the complex task of accounting for pollutants other than carbon dioxide, for example, Folke et al. (1997), Wackernagel et al. (1997), Barrett et al. (2002), though they remain excluded from national footprint calculations. The main hurdle to further integration of pollution accounting would seem to be a lack of reliable research data on the complex way in which pollutants interact and affect bioproductivity. Also, a pollutant can have a range of different impacts on the environment and impacts might only be local thus making it difficult to find an acceptable global average. Further discussion on this issue is contained within a paper by Holmberg, Lundqvist, Robért and Wackernagel (1999).

There is also some confusion amongst critics as to what the footprint is intended to account for. The footprint typically accounts for only those resources that are part of the biosphere's cycles. It is implicitly assumed that the use of heavy metals and hazardous chemicals (those which are persistent, bio-accumulative or toxic) should either be eliminated or must be handled in totally closed loops which do not involve release into the natural environment. Studies have shown that the impacts on bioproductive capacity of, for example, heavy metals are massive and usually swamp other effects of consumption. The natural assimilation rate of copper, for example, is 42 mg per square metre per year. The footprint of a kilogram of copper would therefore be 2.38 ha-years. The footprint of a kilogram of PCBs is an impressive 2,000 ha-years (Krotscheck & Narodoslawsky 1996).

Applying carrying capacity concepts to human populations is flawed. Evidence has shown that (a) humans, unlike other animals, can and do increase the carrying capacity of their environment to meet their needs and (b) certain regions and communities seem to be living beyond their local carrying capacity now with few ill effects.

Criticism (a) is based on a misunderstanding of how footprinting accounts for changes in biocapacity. As the footprint is a 'snapshot' measure, reflecting the supply and demand at the time of the analysis, future effects (such as increases or decreases in biocapacity) would only become apparent in subsequent analyses.

Criticism (b) ignores the fact that populations can exceed local carrying capacity either temporarily, by running down natural capital, or more permanently by importing or appropriating capacity from elsewhere. Take the example of a fishing community dependent on a local lake for their food. They can over-fish the lake, temporarily increasing supply, by catching smaller and smaller fish. This will impact on the ability of the fish population to sustain itself leading to decline in stocks. This is of course what has happened on a wider scale in European sea waters where arguments have raged over the gauge of fishing nets which will allow the immature females to escape. Another option for the fishing community is to simply import produce from elsewhere, either fish or another protein substitute, thus appropriating carrying capacity from elsewhere.

The very process of aggregating land types to calculate a footprint assumes substitution – yet this is not possible.

Aggregating information into a single 'umbrella' indicator need NOT imply that the elements being measured are interchangeable, merely that they are being measured in comparable units. For example, WRME (Wood Raw Material Equivalents) is a common unit used for aggregating the consumption of different types of wood. Aggregating in this way does not imply that, for example, hardwood can be replaced by softwood in all building applications.

Carrying capacity is irrelevant since resource yields can be increased in the case of renewable resources, and depletion profiles can be extended by technology in the case of non-renewable resources.

Indeed, carrying capacity can be altered: both eroded as in the case of desertification, and enhanced as in the case of careful management schemes. That's why ecological footprints are always compared to the biocapacity of a given year (as mentioned earlier). In fact, as footprint accounts point out, technological efficiency is one possible strategy to reduce humanity's draw on nature (as long as the efficiency gains are not outpaced by an increase in consumption).

Carrying capacity calculations have limited relevance where trade is possible since the scarce resource can be imported in exchange for another asset in which the exporting nation has a comparative advantage.

Far from being irrelevant, national footprint accounts are useful for making the trade in ecological capacity more visible. They do this by quantifying 'imports' and 'exports' using globally compatible area units (called global hectares). If resources do become more abundant as a result of increased global yields (rather than merely a shift in the supply chain) then this is reflected in the accounts.

Footprint accounts are not anti-trade – as has been claimed – any more than financially valuing imports and exports can be said to be protectionist.

Certain economies that are highly urbanized (Netherlands, Singapore, Hong Kong) can never be sustainable since they can never meet their ecological demands from their own land.

Of course, urbanised economies are more likely, by definition, to need to import resources to meet their needs due to the lack of available local supply coupled with high demand. This does not mean they can never achieve sustainability, it just means that they are most likely to have to rely on imported ecological capacity. In some ways, urban developments are potentially more sustainable than rural ones. Mobility needs are generally less, for example.

Footprinting is a survivability concept not a sustainability concept. Survivability is about maximizing the time available on Earth for human species, independently of the quality of that existence.

Certainly footprint estimates are a *minimum* requirement for sustainability. In other words, living within global carrying capacity is necessary but not sufficient for sustainability. It may be desirable to increase the footprint to allow for a higher quality of life – especially for the majority of the world's population that currently exist on a footprint below the average earth share.

Calculating the fossil fuel footprints in terms of area needed to absorb the corresponding CO_2 is inadequate according to some critics.

The notional forest area included for CO_2 sequestration represents the degree by which the planet's forest areas would need to be larger in order to cope with anthropogenic CO_2 output. Finding other ways to combat atmospheric CO_2 accumulation could easily be integrated and indeed would open dramatic possibilities for reducing humanity's footprint. Calculations for various forms of renewable energy are included in Chambers et al. (2000).

Another method of calculating the fossil fuel footprint is to assess the biological area necessary to produce a biomass substitute. This would lead to even larger footprints.

There are substantial uncertainties about how to calculate the land areas required to offset waste flows.

The science of accounting for various pollutants is in its early stages and omitting these footprint studies underestimates the environmental impacts of waste and pollution. Examples of studies where the footprints of wastes have been included are referred to earlier.

Footprint accounts make no distinction between land uses that are sustainable and those that are not.

This is correct. But as mentioned previously, changes in productivity due to unsustainable land use do appear in future estimates of biocapacity. If activities in one year lead to an increase in desertification, for example, then the bioproductive supply will decrease in subsequent years. This would decrease the yield factor of natural products and lead to a higher footprint due to unsustainable land use.

2.3.7 Current use of the Ecological Footprint by regions and local authorities

At present, there is a growing number of local authorities who have conducted an ecological footprint for their local authority area and are applying the results. One of the first ecological footprints of a local authority was undertaken for the Isle of Wight. Since this study, an ecological footprint of Liverpool, York, five Scottish cities, Angus, and two local authorities in Lincolnshire, Herefordshire and Oxfordshire have been undertaken. The islands of Jersey and Guernsey have also been footprinted. At the time of writing several other local authority studies are at the proposal stage and are likely to proceed.

At present, most of the studies are being used for educational and awareness-raising purposes. At the same time many of the local authorities are keen to undertake an ecological footprint on a regular basis to use the approach as a monitoring tool for the local authority.

As a policy tool, the ecological footprint is still in its infancy. York City Council's waste department are currently considering its application for analysing the impact of their waste strategies. The Local Agenda 21 officer is also keen to build the ecological footprint into various policy decision making processes within the council. One of the difficulties that the local authorities have faced is the difficulty to update the figures and develop scenario internally within the council. Hence, the ecological footprint software and manual for this project has attempted to overcome this problem.

On a larger scale, the use of the ecological footprint has been more widespread. A project, starting soon, will produce an ecological footprint for every regional government area in the UK[9]. The Welsh Assembly has adopted the ecological footprint as one of their key indicators for sustainable development.

In conclusion, only a small group of local authorities have currently undertaken an ecological footprint study. However, there has been a growing interest from other local authorities who see the value in obtaining an indicator that will provide relevant information to the general public and monitor the effectiveness of past and future policy decisions.

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[9] The project "Ecological Budget UK" is due to start in January 2004