Measuring the sustainability of a national economy. The application of three measures of sustainability to Ireland.

Robin Curry[*a], Cathy Maguire[b], Jim Baird[c]

[a]*Institute for a Sustainable World, Queens University Belfast, BT7 1NN;* [b]*European Environment Agency;* [c]*School of Engineering and Built Environment, Glasgow Caledonian University*

An assessment of the sustainability of the Irish economy has been carried out using three methodologies, enabling comparison and evaluation of the advantages and disadvantages of each, and potential synergies among them. The three measures chosen were economy-wide Material Flow Analysis (MFA), environmentally extended input-output (EE-IO) analysis and the Ecological Footprint (EF). The research aims to assess the sustainability of the Irish economy using these methods and to draw conclusions on their effectiveness in policy making both individually and in combination. A theoretical description discusses the methods and their respective advantages and disadvantages and sets out a rationale for their combined application. The application of the methods in combination has provided insights into measuring the sustainability of a national economy and generated new knowledge on the collective application of these methods. The limitations of the research are acknowledged and opportunities to address these and build on and extend the research are identified. Building on previous research, it is concluded that a complete picture of sustainability cannot be provided by a single method and/or indicator.

Keywords: indicators; sustainability; ecological; footprint; material flow analysis; input-output analysis; Ireland

Introduction

In 1987, the Bruntland report defined what has become the starting-point for future definitions and discussions of sustainable development; 'development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development 1987). Following this, in 1992, the United Nations Conference on Environment and Development (Agenda 21) called for indicators to be developed to provide an evidence base for sustainable development decision-making at all levels (United Nations 1992). One area of focus for subsequent discussions of what constitutes sustainability and, in particular, the measurement of sustainability and what should be measured, has been attempts to further refine the analysis of sustainability in terms of weak and strong sustainability. Weak sustainability derives from economic theory, by extending economic accounting systems to

[*] Corresponding author. Email: r.curry@qub.ac.uk.

non-renewable resources, and has a number of underlying assumptions, including that natural resources are super-abundant, the elasticity of substitution between natural and produced capital, and that technological progress can increase the productivity of the natural capital stock faster than it is being depleted, while strong sustainability contends that natural capital is largely non-substitutable (Dietz and Neumayer 2007). This delineation of sustainability based on the concept of natural capital has significant implications for the development of measures and indicators of sustainability and has directly informed their development. The interpretation of what functions or systems constitute sustainability has, in part, driven the development of a range of methods and/or indicators for measuring progress towards sustainable development since Agenda 21.

Examples of the methods include Material Flow Analysis (MFA) (in its many guises), Physical Input-Output Analysis (PIOT) (Stefan and Klaus 2004), Environmentally-Extended Input-Output Analysis (Duchin and Steenge 2007), the Ecological Footprint (Rees *et al*. 1996), Environmental Space (Weterings *et al*. 1994), Assimilative Capacity (Organisation for Economic Co-operation and Development 1991) and Human Appropriated Net Primary Production (HANPP) (Haberl 1997). Attempts have been made to evaluate the relative strengths and weaknesses of these indicators, including the use of SWOT analysis and the RACER criteria (Relevant, Accepted, Credible, Easy to monitor, Robust) (Lutter and Giljum 2008), developed as part of the European Commission impact assessment guidelines, to thirteen potential tools and indicators. The research concluded that four aggregate indicators were required as complementary tools capable of monitoring the environmental impact of natural resource use: Ecological Footprint (EF), Environmentally Weighted Material Consumption (EMC), Human Appropriation of Net Primary Production (HANPP) and Land and Ecosystem Accounts (LEAC) (Best *et al*. 2008). An application of eight measures of development and/or sustainability for France (green national net product, Genuine Savings, Ecological Footprint, Indicator of Sustainable Economic Welfare, Genuine, Progress Indicator, Pollution-sensitive Human Development Indicator, Sustainable Human Development Indicator and French Dashboard on Sustainable Development), concluded that a single indicator could not give a complete view of sustainability (Nourry 2008), while Wiedmann *et al*. (2010) refer to the truism that there is no best model as such, but only a best model for a specific purpose. This generates the proposition that forms the starting point for this research, namely, that a single method cannot provide a complete picture of sustainability. Therefore, research is required into the application and use of different methods and combinations of methods, in an effort to generate new knowledge on both the optimum combination of methods for measuring sustainability and, possibly more importantly for the research community, learn lessons on the research needs generated by the need to combine methods. Thus, while this research uses the Irish economy as a case study, the results and recommendations for future research priorities are applicable to sustainability research and policy more generally.

Background

There has been limited use of Material Flow Analysis (MFA) in Ireland, with a prototype methodology developed and applied to fossil fuels at a national level and regionally to water flows (O'Leary and Cunningham 2006), and urban applications of the Ecological Footprint (EF) (Walsh *et al*. 2006). In Northern Ireland, the Northern Limits project provided the first regional material flow analysis for Northern Ireland and assessed the impacts of consumption using the Ecological Footprint (Curry *et al*. 2004, 2011). Carried out as part of the UK Mass Balance programme, this built on a range of other studies which combined Material Flow Analysis with Ecological Footprint analysis, including studies for London, Wales and Scotland (Linstead and Ekins 2001, Jones 2006).

As part of this research project, the Northern Ireland MFA and EF analysis were updated and combined with the Ireland MFA and EF, to create an All-Island Material Flow Analysis and Ecological Footprint. The results of this analysis are set out in the final project technical report (Curry and Maguire 2008). As a consequence of the requirement to integrate the MFA and EF of the Republic of Ireland with the Northern Ireland analysis, a baseline year of 2003 was adopted to ensure the compatibility of the Northern Ireland, the Republic of Ireland and all-Island analyses. The rationale for the inclusion of Environmentally-Extended Input-Output Analysis to the research was to enable the evaluation of any additional benefits provided by the extension of the MFA using EE-IO.

Aims and methodology

This research had the following aims:

1. to assess the sustainability of the Irish economy using economy-wide Material Flow, Environmentally-Extended Input-Output, and Ecological Footprint analysis;
2. to draw conclusions on the usefulness of these methods for policy making both individually and in combination, and
3. to identify and make recommendations on future research priorities.

The rationale for the combination of methods for the research lay both in the recognition of material flows as a starting point for environmental impacts, and the recognition of the potential complementarities between the three methods. Material Flow Analysis creates a mass balance framework which quantifies the material flows within and in and out of the economy, and forms the basis of a range of higher level indicators. The combination of MFA with EE-IO allows the incorporation into the analysis of the service sectors and indirect material consumption, and the allocation of material flows to final demand. The methodological basis of the Ecological Footprint (EF) is the quantification of resource consumption in terms of mass or material flows, and the conversion of these material flows into land area (Wackernagel *et al*. 1999, Monfreda *et al*. 2004). The EF sets these flows in the context of sustainability and provides a measure of the ecological limits and pressures associated with these flows. The EF has the potential to complement the MFA approach not only by setting resource consumption into a sustainability context, but also by allowing the communication of this information in a way that is easily understood by policy and decision makers.

Economy-wide Material Flow Analysis

The term Material Flow Analysis (MFA) covers a range of approaches which aim to quantify physical flows into, within and out of the economy and can range from economy-wide MFA to substance flow analysis (Daniels and Moore 2001). The theoretical basis of the MFA approach combines systems analysis with the mass balance/material balance principal of the conservation of matter, derived from the first law of thermodynamics (Hinterberger *et al*. 2003). The first national material flow studies emerged in the early 1990s (Fischer-Kowalski and Hüttler 1998) and these were followed by a rapid acceleration in interest in the field, largely based around efforts to standardise methods. The publication of 'Resource Flows: The material basis of industrial economies' in 1997 took the first step towards developing harmonised methods for measuring the physical transactions in an economy based on the financial accounts for measuring economic flows set out in the System of National Accounts (SNA) (Adriaanse *et al*. 1997) and this was followed by the Weight of Nations, which completed the material cycle by documenting and analysing the material output flows (Matthews *et al*. 2000). The quantification of material flows forms the basis of material flow account indicators such as total material requirement (TMR), direct material input (DMI) and direct material consumption (DMC) (Bringezu *et al*. 2003, Bringezu 2006). With the publication of the Eurostat standards and guidance (Statistical Office of the European Communities 2001, Weisz *et al*. 2007), MFA's offers a common source of data that technical experts can use to set targets and track the effectiveness of environmental policies (Statistical Office of the European Communities 2006). A recent analysis of the state-of-the-art in economy-wide MFA concluded that the method has reached a maturity that provides a sound basis for evaluating national and international policies for sustainable resource use (Fischer-Kowalski *et al*. 2011). However, a number of limitations in the methods have been identified, including the data-intensive and arduous process of compiling the material flow database, that every material flow is converted to the same units (one tonne of toxic waste is treated the same as one tonne of stone), and that there is no method for estimating the environental impacts of the flow (Commission for Environmental Cooperation 2001). From our own experience with respect to environmental policy making, we would cite additional flaws as a lack of understanding of the methodology among policy makers and, most importantly, the weak policy relevance of the MFA derived indicators (Curry *et al*. 2011).The economy-wide material flow accounts for Ireland were calculated using guidance published by the Statistical Office of the European Communities in 2001. The guidance defines the MFA in terms of the flows between a given economy and the environment and provides a range of concepts, definitions and classifications. It defines the system boundary for economy-wide material flow accounts as follows:

1. The extraction of primary (i.e. raw, crude or virgin) materials from the national environment and the discharge of materials to the national environment;
2. The political (administrative) borders that determine material flows to and from the rest of the world (imports and exports). Natural flows into and out of the geographical territory are excluded.

The guidance further describes a material balance accounting scheme for the classification of the flows, which is set out below:

Classification of the flows:

A Resource Flows in	+	B Material Production	-	C Resource Flows out	=	D Net Addition to Stock

A is equal to material imports + product imports
B is equal to material production
C is equal to material exports + product exports + waste production + emissions to air + dissipative outputs of products
D is equal to Net addition to stock
(Details of the classifications and data sources used for the MFA are provided in Notes).

Environmentally Extended Input-Output Analysis
Input-output analysis is an economic tool developed by Leontief (1986), which quantifies inter-industry or sector monetary transactions between the sectors of an economy, using an inverse matrix-based approach, to capture the interactions among all of the industries comprising an economic system. The use of IO for environmental analysis involves the extension of the monetary IO tables using coefficients to represent, for example, material flows or waste production, in a process referred to as Environmentally-Extended Input-Output Analysis (EE-IO). The benefits ascribed to EE-IO include that it allows for the impacts of imports to be considered separately from the impacts of domestically produced goods, the ability to reflect the interrelationships between industries and the capture of indirect effects (Duchin and Steenge 2007). EE-IO has been used extensively to estimate environmental emissions and impacts, including the Ecological Footprint (Bicknell *et al*. 1998, Wiedmann *et al*. 2006, Curry and Maguire 2011), waste, nitrogen (Wier and Hasler 1999), land disturbance (Lenzen and Murray 2001), food production chains (Kytzia *et al*. 2004) and energy requirements of households

(Lenzen *et al*. 2004). A review of peer reviewed articles on environmentally-extended input-output analysis identified over 50 articles relating to EE-IO, noting that its use in ecological footprint analysis had increased rapidly (Hoekstra 2010). However, despite the clear strengths of the method in terms of allocating emissions and impacts, a range of limitations are associated with EE-IO. These include uncertainties of basic source data due to sampling; reporting and imputation errors; the assumption that foreign industries are perfectly homogeneous; the assumption of proportionality between monetary and physical flows; the aggregation of input-output data over different producers; the aggregation of input output data over different products supplied by one industry; and the truncation of the gate-to-grave component of the full life cycle (Lenzen 2001). Supply and Use and Input-Output tables for 2000 (Central Statistics Office 2006), were combined with the data on material inputs for 2003 to produce environmentally extended tables using the methodology in Simmons *et al.* (2006). The extension of the MIOT was carried out in terms of physical units, in this case tonnes. The first step of the methodology is adding the physical information into the I-O table by assigning the physical data to the industrial sector that represents the entry point of that data into the economy, or that represents the best initial and direct association between the physical data and industrial sectors. Full details of the methodology for allocation physical data to I-O sectors and the environmental extension of the I-O tables, including calculation of vectors, is given in Curry and Maguire (2008) and available for download from the EPA SAFER Archive (Environmental Protection Agency 2012).

The Ecological Footprint

Developed in the early 1990s by William Rees and Mathis Wackernagel, Ecological Footprinting has risen to prominence as an indicator of sustainability (Rees *et al*. 1996). The Ecological Footprint (EF) has been described as an accounting tool that adds up human impacts (or use of ecological services) in a way that is consistent with thermodynamics and ecological principles. The EF translates consumption into total area of productive land and water ecosystems required to produce the resources that the population consumes and assimilate the wastes that the population produces (Rees 2000). It does this by taking the resource consumption of a particular population in terms of mass units and converting this into land units (with the exception of built land and land appropriated by transport infrastructure) (Hubacek and Giljum 2003). The Ecological Footprint originated as a tool to support regional and local sustainability (Levett 1998, Wackernagel 1998), and has been applied in numerous studies in recent years in an ever growing range of uses, including the assessment of national and global sustainability (Loh and Goldfinger 2006, Barret *et al*. 2007, Humphrey *et al*. 2008) and local environmental policy and administration (Aall and Norland 2002, Aall and Thorse 2005), and a growing range of other applications, including the sustainability of products (Huijbregts *et al*. 2008, Cerutti *et al*. 2010), activities, a range of organisation types, in sustainable construction planning (Nye and Rydin 2008), and as a planning tool at the local level (Moos *et al*. 2006). The Ecological Footprint has been adopted as a headline indicator by a number of governments and regional assemblies including the Welsh Assembly (WWF-Cymru 2005) and Northern Ireland Assembly (Environmental Policy Group 2006). However, despite the popularity of the Ecological Footprint among both the policy and research communities, the strengths and weaknesses of the Footprint have been the subject of ongoing debate in the literature, with Fiala (2008, p.1) describing the use of the footprint in arguments about sustainability as 'bad economics', while Cerutti *et al.* (2010, p.2) describe it as 'scientifically robust'. Specific criticisms have included the static nature of footprint analysis (Moffatt 2000), the aggregation and allocation methodologies (van den Bergh and Verbruggen 1999, Hubacek and Giljum 2003), and a lack of suitability for forecasting and modelling (Moffat *et al*. 2001). Moffatt (2000) made a number of recommendations for improvements to the policy relevance of the Ecological Footprint, including combining with input/output or natural resource accounting. The ongoing development methods for allocating the Ecological Footprint using EE-IO is one of the most dynamic areas of research in Ecological Footprint analysis. In 2006, a method was proposed to combine existing National Footprint Accounts with input-output analysis, which disaggregated the National Footprint Account (NFA) using input-output analysis. The methodology formed the basis of the Stockholm Environment Institute Resources and Energy Analysis Programme (REAP) model, which has been applied extensively in the UK at both national and regional levels (Curry and Maguire 2011). A review of the Ecological Footprint as a headline indicator for sustainability decision-making concluded that none of the methods reviewed could address all issues and questions and recommended that the Ecological Footprint be more closely aligned with the UN System of National Accounting (Wiedmann and Barrett 2010). Ecological Footprint analyses are usually presented in conjunction with Biocapacity, to allow the consumption of resources to be compared to their availability, that is, the demand on nature (the EF) and the ecological supply (BC). Biocapacity has been described as 'the counterpart of the Footprint' (Wackernagel *et al*., 2005, p.18) and a method to answer the question: 'How many of the renewable resources have been made available by the biosphere's regenerative capacity' (Schaefer *et al*. 2006, p.6). The biocapacity of a nation is the sum of its bioproductive areas, and this is converted into global hectares (a common unit that encompasses the average productivity of all the biologically productive land and sea area in the world in a given year) by multiplying the area by country-specific equivalence and yield factors. It is the combination of FE and BC which enables the sustainability assessment, and arguably, forms the basis of much of the footprint's power as a metaphor for sustainability, as it places the consumption in the context of globally available resources – by demonstrating how far above globally available biocapacity a nation's consumption is, it allows the calculation of the number of planets which would be required to sustain this level of consumption and hence the principle of one planet living. The annual National Footprint Accounts (NFA), published biennially as part of WWF's Living Planet Report series, are a series of EF calculations for 150 nations, prepared by the Global Footprint Network, which use an EF methodology known as the compound or top-down approach (Loh and Goldfinger 2006). The compound approach captures all resource use, including trade, within a geographical boundary, and is measured at a national level. A component-based methodology was used to re-analyse the NFA and disaggregate the results into policy-relevant, activity-based sections. In this approach, EF values for certain activities (for example, food consumption) are pre-calculated using data appropriate to the country under consideration (Simmons *et al*. 2000). The Ireland data used for the Ecological Footprint analysis is shown in Table 1.

Table 1: Ireland data used for the Ecological Footprint analysis

Component	Data Year	Source:
Domestic Energy	2003	SEI Energy Balance 2003
Services Energy	2003	CSO Statistics Yearbook 2004
Materials & Waste	2003	2002 Trade (NFA 2005) & 2003 Waste (EPA 2003)
Food	2002	FAO Food Balance Sheet 2002
Personal Transport	2002	EU: Energy & Transport in figures 2004
Built Land	2002	National Footprint Accounts (NFA) 2005

Results

The assessment of the sustainability of the Irish economy has been carried out using the three methodologies, enabling comparison and evaluation of the advantages, disadvantages of each and potential synergies among them.

Economy-wide MFA of Ireland

The completion of the first economy-wide MFA for Ireland provided a comprehensive description of the material flows between the environment and the economy as well as within the economy (production and consumption). The economy wide Material Flow Model of Ireland for the year 2003 is shown in Figure 1. The flows of materials and products were quantified by industrial sector (NACE Rev.1.1), where total inputs equals total outputs and net addition to stock (net addition to stock is a balancing item as calculation of stock was not included in the analysis).

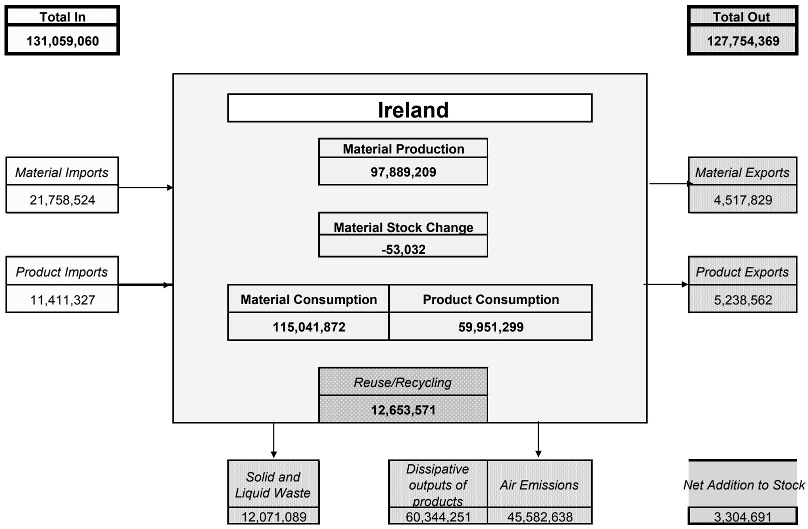


Figure 1: Material flow model of Ireland in 2003 (tonnes)

Material Flows

In 2003 Ireland consumed over 115 million tonnes of materials. These materials were either consumed directly or used in the manufacture of a product. The MFA identified those industrial sectors, which are most significant in terms of resource consumption, showing that in terms of direct material consumption the mining and quarrying sector consumed the greatest amount of materials, followed by the agricultural sector. The breakdown of material flows in Ireland for the year 2003 is shown in Table 2.

Table 2: Material flows through Ireland in 2003 (tonnes)

Description	Production	Import	Export	Net Supply	Stock change	Consumption
Total materials	97,889,209	21,758,524	4,517,829	115,129,905	-53,032	115,041,872
Of which						
Agriculture	39,956,337	2,258,366	1,342,475	40,872,228	-101,000	40,736,228
Forestry	2,73,6606	170,756	349,335	2,558,027	No data	2,558,027
Fishing	338,640	6,609	106,410	238,839	No data	238,839
Coal, lignite and peat extraction	332,406	1,315,370	9,306	1,638,470	106,256	1,744,726
Oil and gas extraction	562,440	13,077,892	1,548,216	12,092,116	-58,288	12,033,827
Metal ores extraction	943,795	3,421,099	503,363	3,861,531	No data	3,861,531
Other mining and quarrying	53,018,985	1,508,432	658,723	53,868,694	No data	53,868,694

Product Flows

Table 3 provides a breakdown of product flows in Ireland in 2003. Several sectors had to be combined for reasons of confidentiality, namely NACE 23 (coke, petroleum products and nuclear fuel), NACE 28 (fabricated metal products) and NACE 32 (radio, television and communications). The Irish economy consumed nearly 60 million tonnes of manufactured products, with the food and beverages sector consuming 9.8 million tonnes (19%), the medical instruments, watches and clocks sector consuming 12.8 million tonnes (20%). The non-metallic mineral products sector was the largest consumer of products with 19.7 million tonnes (33%). This sector includes products such as concrete, bricks and glass.

Table 3: Product flows through Ireland in 2003 (tonnes)

Description	Production	Import	Export	Net Supply	Consumption
Total products	52,569,193	11,411,327	5,238,562	58,741,951	59,951,299
Of which					
Food and beverages	8,620,970	3,296,235	2,285,849	9,631,656	9,873,292
Tobacco products	13,905	10,951	8,349	16,507	16,507
Textiles	71,217	43,101	9,170	105,148	105,333
Leather clothes, wearing apparel and fur	32,766	48,558	8,995	72,329	73,319
Leather luggage, handbags	233	17,731	1,853	16,101	16,185
Wood and cork products	609,561	171,333	62,169	718,725	718,725
Paper, pulp and paper products	402,183	251,983	42,932	611,234	611,234
Publishing, printing and recording media	76,034	63,776	44,853	94,956	102,487
Chemicals and chemical products	1,638,352	828,457	267,822	2,198,980	2,336,187
Rubber and plastic products	728,173	285,544	138,454	875,263	895,474
Non-metallic mineral products	19,521,101	1,400,964	1,147,248	19,774,816	19,796,504

Basic metals	4,628	13,179	1,370	16,437	16,556
Machinery and equipment n.e.c.	5,173,461	220,796	74,082	5,320,175	5,335,137
Office machinery and computers	209,842	231,905	227,835	213,912	325,113
Electrical machinery and apparatus n.e.c	23,475	57,967	11,567	69,876	70,019
Medical instruments, watches and clocks	12,836,984	21,705	197,040	12,661,648	12,837,399
Motor vehicles, trailers and semi-trailers	19,699	273,517	22,564	270,651	271,607
Other transport equipment	5,156	10,399	1,465	14,091	14,723
Furniture and miscellaneous manufactured products	215,174	151,775	70,222	296,727	311,878
Combination of 23, 28 and 32.	2,366,291	4,011,152	614,723	5,762,720	6,223,619

MFA indicators

A set of indicators was calculated from the MFA to provide a picture of the industrial metabolism of Ireland and allow comparison in a standardised way with other countries and over time. MFA indicators can be divided into three main categories; input, output and consumption. In addition, balancing and efficiency indicators can also be calculated (Efficiency indicators relate MFA indicators to economic indicators such as GDP). Each of the indicators below was calculated for Ireland as a whole and on a per capita basis.

1. Direct Material Input (DMI) measures the direct input of materials (in terms of their mass) for use into the economy, i.e. all materials which are of economic value and are used in production and consumption activities. DMI equals domestic extraction plus imports.
2. Domestic Material Consumption (DMC) measures the total amount of material used directly in the economy. DMC equals DMI minus exports.
3. Domestic Processed Output (DPO) is the total weight of materials extracted from the domestic environment or imported, which have been used in the domestic economy before flowing to the environment. Included in DPO are emissions to air, waste disposed in landfills, material loads in wastewater and materials dispersed into the environment as a result of product use.
4. Direct Material Output (DMO) represents the total quantity of material

leaving the economy after use either towards the environment or outside the national boundary. DMO is the sum of DPO and exports.

5. Physical Trade Balance (PTB) measures the physical trade surplus or deficit of an economy and PTB equals imports minus exports.

6. Resource Efficiency Indicators measure the resource productivity and intensity of the economy. Resource productivity is the contribution to GDP at constant prices generated per tonne of domestic extraction (DE), material input and material consumption (GDP/MFA indicator). Resource intensity is the tonnes of domestic extraction, material input and material consumption needed to generate one unit of GDP at constant prices (MFA indicator/GDP). Table 4 shows the values of the indicators derived from the MFA of Ireland.

Table 4: MFA derived indicators for Ireland 2003.

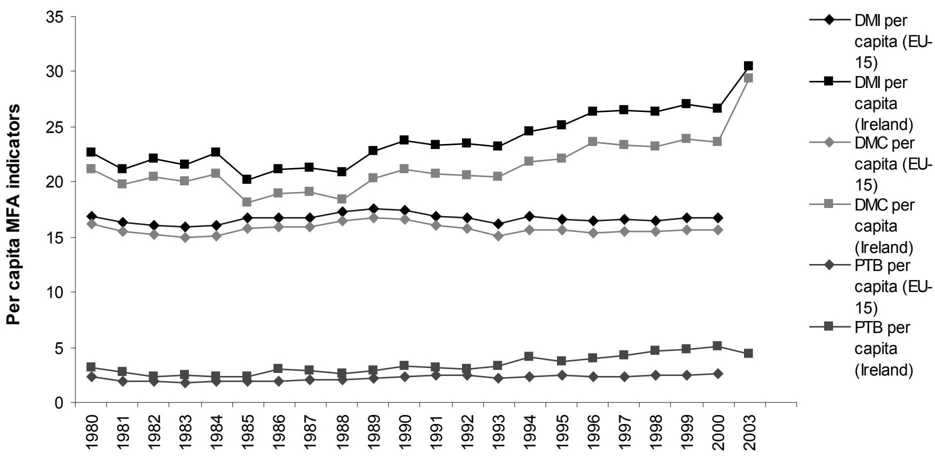
Indicator type	Indicator	Unit	Value
Input	DMI	Tonnes	119,647,733
	DMI per capita	Tonnes per capita	30.5
Consumption	DMC	Tonnes	115,129,904
	DMC per capita	Tonnes per capita	29.4
Output	DPO	Tonnes	117,997,978
	DPO per capita	Tonnes per capita	30.1
	DMO	Tonnes	127,137,366
	DMO per capita	Tonnes per capita	32.5
Balancing	PTB	Tonnes	17,240,695
	PTB per capita	Tonnes per capita	4.4
Resource productivity	GDP/DE	Euros per tonne	998
	GDP/DMI	Euros per tonne	817
	GDP/DMC	Euros per tonne	849
Resource intensity	DE/GDP	Tonnes per euro	0.001
	DMI/GDP	Tonnes per euro	0.00122
	DMC/GDP	Tonnes per euro	0.00118

Comparison of Ireland with other European countries

These indicators provide a snapshot of the industrial metabolism of the Irish economy in 2003. However, indicators work more effectively when historical data are available to detect trends or data available to enable comparison with other countries. Therefore, the data from Ireland was combined with a time series of MFA indicators for the EU-15 (Moll *et al*. 2005), to place the Irish indicators in context (Figure 2). While Ireland may have the lowest total DMI amongst the EU-15, on a per capita basis it is higher than many countries, including Germany, France and the UK. In 2000, the average of the EU-15 was about 16.8 (t/cap), while Ireland was well above this at 26.6 (t/cap). From 2000 to 2003, DMI per capita rose to 30.5 (t/cap). Ireland has the fourth highest DMI per capita, with only Finland, Denmark and Belgium/Luxembourg being higher. The major part of the DMI of the EU-15 is formed by non-renewable resources, about 74% in 2000. While the major part of Ireland's DMI in 2003 was formed from non-renewable resources, i.e. 65%, this was less than the European average and may reflect the relatively large input from the agricultural sector. The proportion of DMI comprising of imports has been rising in the EU from around 12% in the 1980s to 16% in the late 90s. In Ireland in 2003, around 22% of DMI was comprised of imports with 60% comprised of fossil fuels. At a European level, DMC has developed in parallel to DMI. DMC has remained fairly constant at around 15.5 tonnes per capita since 1995 onwards. Construction minerals dominate DMC of the EU-15 and there was a 354% increase in domestic consumption of construction minerals in Ireland from 1970-2000. Ireland's DMC has always remained above the EU-15 average and in contrast has been increasing since the early 1990s as shown in Figure 2(A). The DMC per capita calculated in the present study shows a further increase from 2000 to 2003.

A comparison of DMC across the EU-15 revealed that use of biomass, industrial minerals, ores and fossil fuels is determined largely by the structure of the economy rather than by national income or economic performance (Weisz *et al*. 2006). In general DMC is high in countries which specialise in one or more of the material intensive sectors, in Ireland's case this is livestock production. Countries with high levels of livestock farming in the agricultural sector usually have high per capita values of biomass domestic extraction (DE). Livestock production systems are also very biomass intensive as one mass unit of animal products is associated with up to ten mass units upstream primary material inputs. Pasture-based agriculture combined with a low population density in Ireland contributes to the high per capita DMC. The difference between DMI and DMC can reflect physical external trade patterns as the difference is made up by exports. Ireland's PTB per capita has been above the EU-15 average since 1989 (Figure 2). Only Belgium/Luxembourg has a higher PTB per capita than Ireland. The values calculated in this study show a drop from 2000 to 2003, indicating an increase in physical exports (tonnes of materials and products exported). This decrease in PTB per capita is reflected in the smaller difference between DMI and DMC than in previous years. The PTB also shows that while Ireland may have a relatively high amount of physical exports compared to imports, Ireland is not self-sufficient in its resource basis as physical exports are below imports and domestic extraction is less than DMC.

Resource productivity and intensity.
There are several patterns of development of GDP and DMI. In most high income countries, DMI has remained fairly constant while GDP is growing. In Ireland DMI is high but has remained so over the course of significant economic growth, reflecting relative decoupling, but Ireland still has a significantly higher materials burden than in other countries. At a European level the economy had been growing steadily while at the same time resource use has remained fairly constant in terms of DMI per capita. This has led to a relative de-coupling of economic growth and resource requirements which is reflected in an increase in resource productivity (GDP/DMI) (Moll *et al*. 2005). The resource productivity and intensity indicators for Ireland and the EU-15 are shown in Figure 2 (B and C). While the resource efficiency of Ireland's economy has been increasing, the above average DMI and below average resource productivity indicate that improvements could be made and there remains a stronger positive link between economic growth and resource use than in some other European countries. Ireland would need to increase its resource productivity by around 25% to reach the EU-15 average. The resource intensity of Ireland's economy has decreased since the 1980s. In 1980, 2.8kg of direct material input was required to contribute €1 to GDP, this fell to 1.2kg in 2000 and 1.12kg in 2003. In 1980, 2.6kg of direct material consumption was required to contribute €1 to GDP, falling to 1.09kg in 2000 with a slight rise to 1.18kg in 2003. Ireland has a higher resource intensity than the EU average, and although it is decreasing faster than the EU-15 as a whole, this decrease had levelled off from 2000 to 2003.



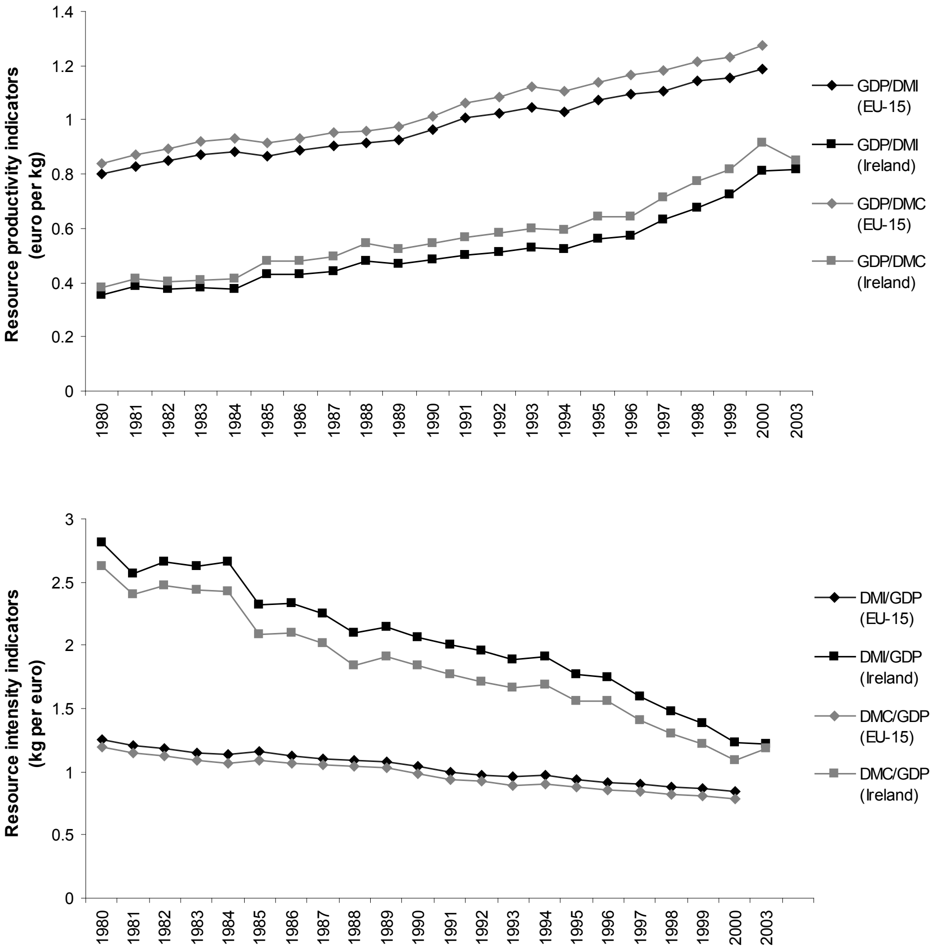


Figure 2: MFA indicators for Ireland and the EU-15 from 1980-2003 (2001 and 2002 are not included) (adapted from EU Zero Study data set b, EuroStat, 2006).

Environmentally-Extended Input-Output Analysis

The EE-IO analysis identified the industrial sectors that are most significant in terms of resource consumption, including both direct and indirect consumption and incorporating the service sectors. Table 5 shows the tonnes of materials that are required by each sector to meet its final demand. Three final demand categories are shown; total, households and for exports. The tonnages represent the allocation of all material inputs based on the economic interactions among sectors. This analysis reveals that the construction sector had the highest material requirement using 36% of all material inputs. The food and beverages sector was the next highest (24%), followed by the non-metallic mineral products sector (9%) and the agriculture, forestry and fishing sector (8%). These sectors together consume over half of all the material inputs to deliver their goods and services.

Analyses were also carried out for all material inputs, biomass, metals, fossil fuels, minerals and imports separately. In each of these analyses, the total material requirement needed to produce total final demand, final demand for households, and final demand for exports, was determined.

Table 5: Total Material Requirements needed to meet final demand (tonnes).

		Total Material Requirements (value allocated tonnes)		
		Total final demand	Households	Exports
1-5	Agriculture, forestry and fishing	8,798,118	4,189,001	5,390,560
10-14	Mining and quarrying products	3,784,691	782,685	2,045,658
15	Food and beverages	26,809,805	5,730,583	20,652,571
16	Tobacco products	26,801	17,071	9,471
17	Textiles	168,181	8,301	158,247
18	Wearing apparel	9,999	2,180	7,703
19	Leather and leather products	38,546	2,209	39,513
20	Wood and wood products (excl furniture)	649,965	249,639	368,648
21	Pulp, paper and paper products	298,944	74,164	205,612
22	Printed matter and recorded media	166,022	3,474	162,246
23, 36	Petroleum and other manufacturing products	3,743,583	1,466,337	1,764,426
24	Chemical products and man-made fibres	3,922,950	14,410	3,892,910
25	Rubber and plastics	259,751	7,231	246,685
26	Other non-metallic mineral products	10,194,857	661,645	9,192,704
27	Basic metals	1,673,541	3,983	165,1161
28	Fabricated metal products	171,633	2,248	158,149
29	Machinery and equipment n.e.c.	380,024	729	361,185
30	Office machinery and computers	809,256	868	801,797
31	Electrical machinery and apparatus n.e.c.	551,402	4,347	536,429
32	Radio, television and communications apparatus	175,264	124	174,222
33	Medical, precision and optical instruments	186,617	48	179,419
34	Motor vehicles and trailers	80,633	313	75,229

35	Other transport equipment	28,637	442	25,803
37	Recycling	679	103	0
40	Electricity and gas	829,720	796,838	205
41	Water collection and distribution	0	0	0
45	Construction work	41,032,023	671,422	0
50	Motor fuel and vechicle trade and repair	45,310	21,011	0
51	Wholesale trade	130,574	51,254	28,514
52	Retail trade and repair of household goods	443,735	443,735	0
55	Hotel and restaurant services	2,562,992	1,517,169	1,045,823
60	Land transport services	72,069	67,318	4,750
61	Water transport services	17,534	3,891	13,643
62	Air transport services	97,621	39,405	58,216
63	Auxiliary transport services and travel agencies	56,711	12,365	44,346
64	Post and telecommunication services	236,734	103,110	123,297
65	Financial intermediation services	124,591	39,285	85,305
66	Insurance and pension services	91,862	44,009	47,853
67	Services auxiliary to financial intermediation	958	958	0
70	Real estate services	2,402,767	2,274,016	0
71	Renting services of machinery and equipment	14,256	6,468	7,788
72	Computer and related services	49,226	0	46,060
73	Research and development services	27,768	0	16,097
74	Other business services	286,449	22,887	236,414
75	Public administration and defence	1,337,999	43,811	0
80	Education	680,140	113,959	0
85	Health and social work services	304,105	45,455	0
90	Sewage and refuse disposal services	1,539	1,539	0
91	Membership organisation services n.e.c.	38,599	8,529	0
92	Recreation	123,429	93,489	17,060
93	Other services	33,320	31,377	1,942
95	Private households with employed persons	77	77	0

Ecological Footprint Analysis

In 2002, Ireland residents' total Ecological Footprint was calculated to be 20.9 million gha, or 5.37 gha per person. The total Ecological Footprint can be broken down into more detailed components for further analysis. This breakdown enables a better understanding of the size of resource demands associated with various aspects of consumption. The Food Footprint was 5.6 million gha – 27% of the total Ecological Footprint – of which 70% was animal-based food; the Direct Energy Footprint was 4.7 million gha – 22% of the total Ecological Footprint – of which 67% was domestic energy use; the Personal Transport Footprint was 3.2 million gha – 15% of the total Ecological Footprint – of which 56% was car travel; the Materials and Waste Footprint was 7.1 million gha – 34% of the total Ecological Footprint; the Built Land Footprint was 0.4 million gha – 2% of the total Ecological Footprint.

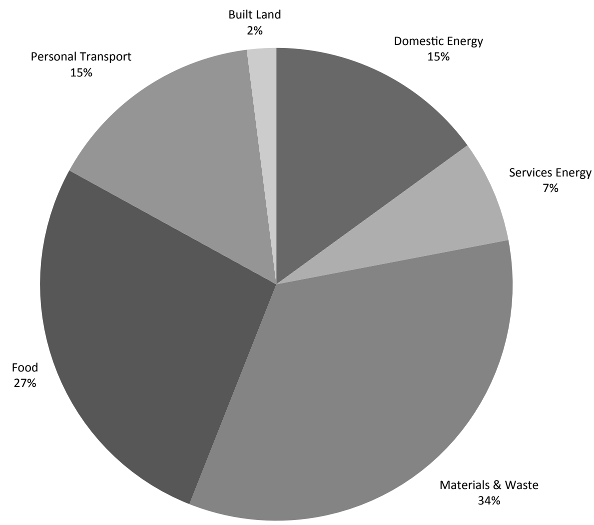


Figure 3: Ecological Footprint of Ireland residents, by component, in 2002

Table 6: Ecological Footprint of Ireland residents by component in 2002

Component	Total Footprint (gha)	Footprint per person (gha/person)	% of Footprint
Ecological Footprint	20,997,870	5.37	100%
Of which…			
Direct Energy	4,684,113	1.20	22%
Of which…			
Domestic Energy	3,142,041	0.80	15%
Services Energy	1,542,072	0.39	7%
Materials & Waste	7,146,213	1.83	34%
Food	5,569,109	1.42	27%
Personal Transport	3,164,162	0.81	15%
Built Land	434,274	0.11	2%

As the Ecological Footprint measures consumption of resources (or final demand), it can be useful to compare the Footprint with other indicators of the economy as a whole. For example, Ireland's Ecological Footprint can be compared with Ireland's Gross Domestic Product (GDP) (Figures 4 and 5).

Figures 4 and 5 show that Ireland's Ecological Footprint and its economy are gradually 'decoupling'. This is shown in Figure 4 as an increasing amount of GDP produced per global hectare consumed, between 2001 and 2003, while Figure 5 shows the resource intensity of Ireland's economy, in terms of the global hectares consumed to generate one million Euros of GDP.

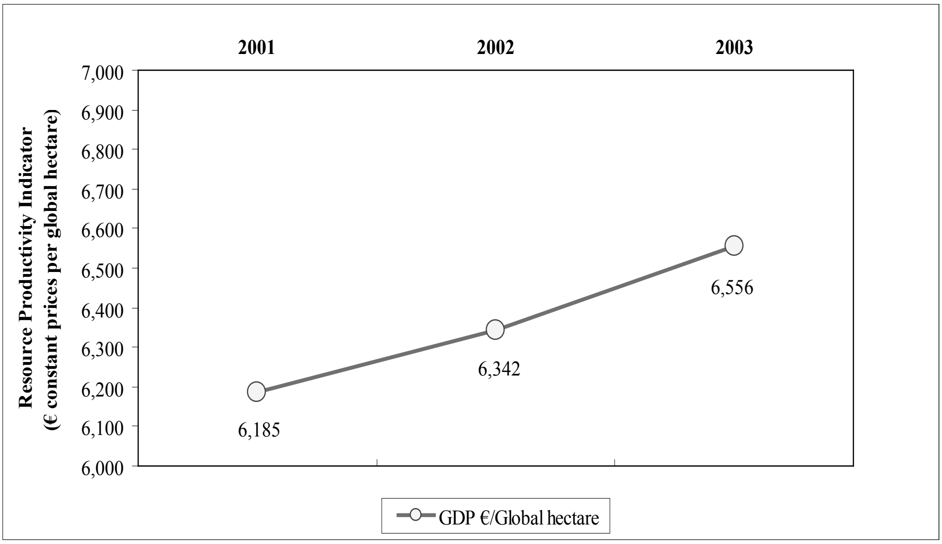


Figure 4: Resource productivity indicators for Ireland, 2001-2003 (The € contribution to Ireland's GDP per global hectare)

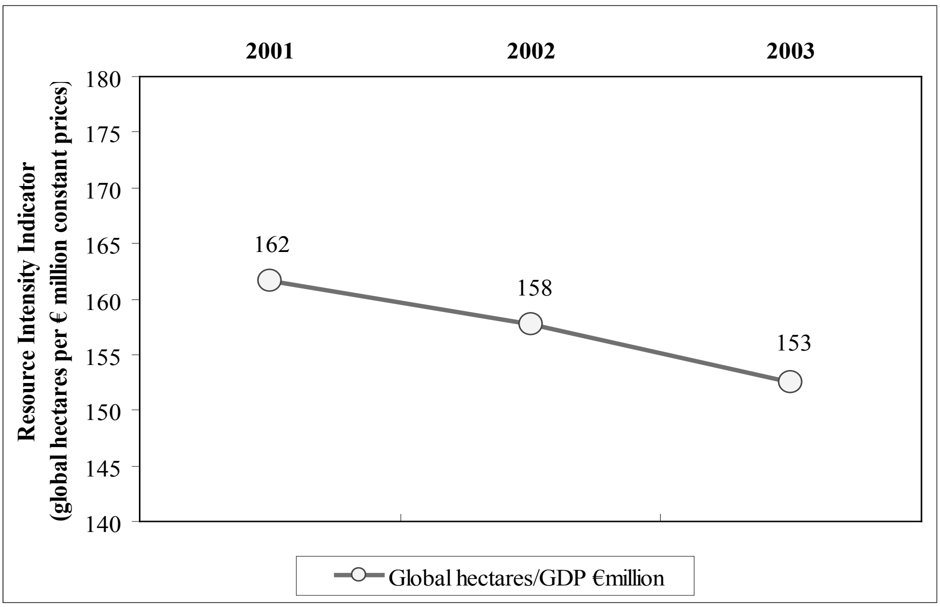


Figure 5: Resource intensity indicators for Ireland, 2001-2003 (The global hectares consumed per €million contribution to Ireland's GDP)

Sustainability Assessment

An ecological footprint measures the demand for natural resources. By comparing this demand within the available supply of natural resources, it is possible to provide a measure of sustainability. The available supply of natural resources in an area is referred to as the 'biocapacity'.

per person biocapacity (gha) =

$$\frac{({}^{L}arable + {}^{Y}arable) + ({}^{L}pasture + {}^{Y}pasture) + ({}^{L}forest + {}^{Y}forest) + ({}^{L}built\ land + {}^{Y}built\ land) + ({}^{L}sea + {}^{Y}sea)}{population}$$

Where:

* L = the area of that area type
* Y = the bioproductivity or yield of that area type

The bioproductivity of the different areas of Ireland was assessed to derive national biocapacity, as shown in Table 7

Table 7: Ireland's Biocapacity in 2002.

Area Type	Bioproductive land of Ireland (gha/person)	Biocapacity of Ireland (gha/person)	Biocapacity of Ireland (gha)	% of Biocapacity
Crop land	0.26	1.29	5,035,298	28
Pasture	1.02	0.94	3,686,379	20
Forest	0.15	0.69	2,700,639	15
Built land	0.02	0.11	419,899	2
Inland fisheries	0.04	0.00001	25	0.0001
Ocean fisheries	3.88	1.58	6,172,768	34
Total	5.36	4.61	18,015,009	100

The Ecological Footprint can be compared with biocapacity derived at either the global, national or regional level. Comparing an Ireland resident's Ecological Footprint (5.37 gha) with Ireland's biocapacity per person (4.61 gha) indicates whether or not the population is living within the means of its national boundaries. The figures show that at a national level, demand for natural resources is more than the available supply. Figure 6 shows the relationship between Ireland's Ecological Footprint and biocapacity from 1961-2002.

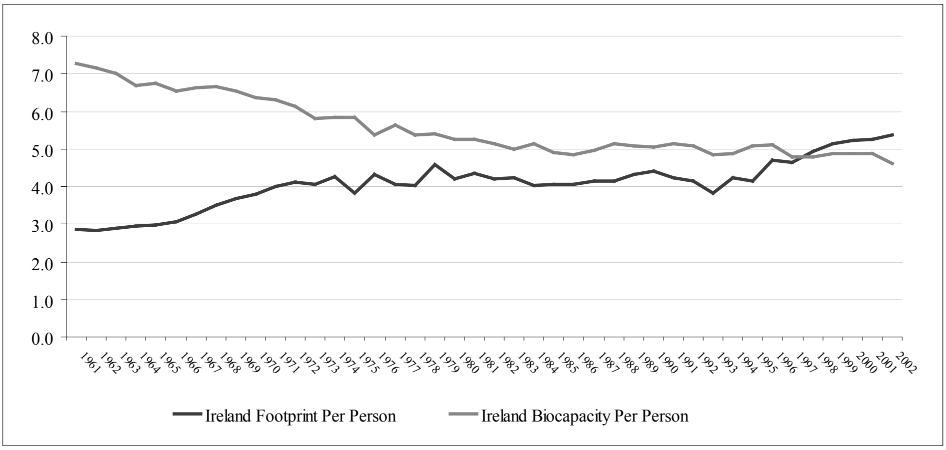


Figure 6: Ireland's Ecological Footprint and biocapacity (per capita), 1961-2002

It is possible to compare the Ecological Footprint with globally available biocapacity as an indication of whether or not Ireland's population is living within environmental limits. These national and global comparisons are shown in Table 8.

Table 8: Local and Global Ecological Sustainability measures for Ireland, 2002

Country	Global hectare (gha/person)	Ireland's footprint as a % of local and global biocapacity
Ireland residents ecological footprint	5.37	
Ireland's biocapacity	4.61	116%
Global biocapacity (earthshare)	1.80	298%

Discussion

The application of the three measures of sustainability to a national economy has provided a range of outputs and insights. The completion of the economy-wide MFA for Ireland provided a comprehensive description of the material flows between the environment and the economy as well as within the economy (production and consumption). This has created a sound material accounting framework, based on mass balance principles and a standardised methodology, which can be built on to enable Ireland to measure its resource efficiency on an ongoing basis. In terms of usefulness for policy making, the MFA has allowed the calculation a range of material and resource flow indicators, which provide a picture of the 'industrial metabolism' of Ireland and allow comparison in a standardised way both with other countries and over time. The time-series comparisons with other EU-15 countries using MFA and resource productivity and intensity indicators, have shown that Ireland had a significantly higher materials burden than other European countries. Although the resource intensity of Ireland's economy has decreased since the 1980s, it still had a higher resource intensity than the EU average, and, although it was decreasing faster than the EU-15 as a whole, this decrease leveled off from 2000 to 2003. However, while the MFA allows the calculation of standardised indicators, a key limitation of the method is that all material flows are treated the same and do not provide a means of estimating the environental impacts of the flows. As such, when used in isolation, economy-wide MFA is often of limited value for policy making.

When the indirect material consumption was included using the EE-IO analysis, construction had the highest level of material consumption, followed by food and beverages, non-metallic mineral products, and then, agriculture, forestry and fishing. The MFA and EE-IO analyses both identified the same areas of the economy as consuming the most materials, namely the provision of building materials and construction; and the provision of food and beverages and agricultural products. Several service sector activities were also shown to have relatively high material requirements such as real estate services and hotel and restaurant services. The use of I-O analysis in combination with the economy-wide MFA not only provides a more complete picture of the industrial metabolism of Ireland, but has added benefits in terms of linking resource accounting with standardised economic accounting systems, namely, the System of National Accounts. The Ecological Footprint analysis has calculated the EF of Irish residents and broken this down into more detailed components for further analysis. It has enabled the calculation of resource productivity and resource intensity indicators for the Irish economy and has allowed the comparison of the Ecological Footprint with globally available biocapacity as an indication of whether Ireland's population is living within the environmental limits of the planet – One Planet Living. In terms of environmental policy making, the Footprint provides a comprehensive (but of course, incomplete) analysis of the sustainability of the economy, breaks down into policy-relevant components and provides a powerful communication tool which can be understood by the public, politicians and policy makers.

Limitations and opportunities

The application of three measures of sustainability to Ireland has provided valuable insights into these methods and their use in combination, enabling comparison and evaluation of the advantages, disadvantages of each and potential synergies between them. A key limitation was the need to integrate with the Northern Ireland and Ireland analyses to create an all-island model, which required the use of the same baseline year for both. However, this provides a valuable opportunity to revisit the analysis, and to allow a comparative analysis of the sustainability of the Irish economy, following the financial crisis in Ireland. Such an analysis could provide valuable insights into how economic recession impacts on measures of sustainability, resource efficiency and raw material consumption.

Conclusions and recommendations

We have described as the starting point for our research, the proposition that there is not a single method and/or indicator that can provide a complete picture of sustainability, and this in turn generated the need for research into the application and use of different methods and combinations of methods. All methods have their advantages and disadvantages. As a standardised method, MFA can be used to benchmark Ireland's performance against other economies and the set of indicators derived from the MFA enable the examination of the resource productivity and intensity of production and consumption patterns. However, the economy-wide MFA does not incorporate directly the service sectors or allocate material flows to final demand. Additionally, while the MFA allows the production of standardised material flow and resource indicators, it is difficult to see how these indicators align with the needs of environmental policy makers. Given that the service sectors are now the fastest growing sectors, from that perspective EE-IO has many attractions. EE-IO also links MFA to standardised economic accounting via the UN System of Environmental and Economic Accounting (United Nations 2003). The increasing use of EE-IO in the calculation of consumption-based footprints offers the possibility of integrating all three methods within one standardised framework.

While the Ecological Footprint was calculated using a standardised method (Global Footprint Network 2006), this is not compatible with standardised economic accounting which creates a barrier to its more widespread adoption by both policy makers and statistical agencies. The EF retains a unique power as both a means of measurement and communication – in the words of Constanza (2000, p.341), 'everyone, it seems, understands land area as a numeraire – even those who have trouble with money or energy as a numeraire'. The publication by a community of active Footprint practitioners and users of a research agenda for improving Ecological Footprint accounts has set out a detailed agenda for further development, and highlighted that a basket of indicators is required by policy makers, and that the need for ongoing development is not unique to the Ecological Footprint (Kitzes *et al*. 2009). If the Ecological Footprint is to realise its potential as both a 'measuring rod and metaphor' (Opschoor 2000, p.363), then further development of the methodology needs to address issues of transparency, standardisation and compatibility with standardised economic accounting. In this respect, a promising area of research is the use of EE-IO to allocate a number of footprint indicators, including Ecological, Carbon and Water (Ewing *et al*. 2012). This can facilitate ongoing methodological development (such as Wiedmann and Barrett's (2010) recommendation for alignment with the UN System of National Accounting) and address the ongoing concerns of statistical agencies. However, while appropriate for allocating footprints at national, and regional levels, EE-IO is not appropriate for all the applications of the footprint and is itself, the subject of ongoing methodological development and criticism, particularly a lack of transparency on data sources (Curry 2011) and conversion factors and the many simplifying assumptions not being made explicit (Turner *et al*. 2007).

The authors have previously recommended the production of standardised guidance on the calculation of regional and national Ecological Footprints, similar to that produced by Eurostat for Material Flow Analysis (MFA) (Curry and Maguire 2011), and based on the insights gained from this research, we would recommend that this be extended to encompass the full range of consumption-based footprints (ecological, carbon and water), and the use of EE-IO for their allocation.

The conclusion that there is not a single method and/or indicator that can provide a complete picture of sustainability, and that the aim of the research programme was to inform policy making, generates as a clear priority, research which can identify the optimum combinations of methods for different policy and decision making contexts and provide guidance on their application. A useful starting point is the categorisation of tools for sustainability assessment developed by Ness *et al.* (2007), while Giljum *et al.* (2010) have suggested a system of resource use indicators and made recommendations for ongoing research needs. Singh *et al.* (2009, 2012) have provided an overview of sustainability assessment methodologies (capturing environmental, economic and social aspects) and have called for a coherent framework for the selection and development of indicators of sustainable development. While all methods are undergoing continuous development and improvement, clear pathways are emerging, specifically the emerging consensus for increased standardisation of methods and alignment with the UN System of National Accounting. A full assessment of the optimum methods and combinations of methods is only possible if the methods are assessed collectively. As we are in the early stages of a process of standardisation and alignment, such a collective assessment allows the identification of synergies (such as overlapping datasets and alignment of different classifications and categorisation systems) and potential trade-offs, and we recommend as a research priority, the development of a standardised framework and guidance for combining methods and indicators. We hope that this research can provide insights for other researchers and help set out the priorities for research to support this important policy area.

Notes

Classifications and data sources for the Material Flow Analysis.

In the Republic of Ireland, industrial sectors are classified by Statistical Classification of Economic Activities in the European Union (NACE Rev.1.1). The main dataset used to derive consumption of products and some materials was ProdCom (List of PRODucts of the European COMmunity). Materials are included under sectors 1 (Agriculture), 2 (forestry), 5 (fishing), 10 (mining and quarrying of coal; extraction of peat), 11 (extraction of crude petroleum and natural gas), 13 (mining of metal ores) and 14 (other mining and quarrying) of NACE. Other sources for materials included agricultural production data for Ireland, obtained from the Central Statistics Office (CSO) in the Statistical Yearbook of Ireland (Central Statistics Office 2004). This sector also includes an estimated biomass input from hay and grass silage and grass grazed by livestock. Data on land area used for each of these activities was obtained from the CSO and this was multiplied by estimates of yield to calculate tonnage of biomass input. Forestry data was obtained from COFORD (Ireland's National Council for Forestry Research Development). Fishing data was obtained from the CSO annual statistics. An additional source of biomass input into Ireland is seaweed harvesting; this is included in FAO harvesting statistics. An estimate of seaweed harvesting and export for 2003 was included. Mining and Quarrying and Extraction of crude petroleum and natural gas were obtained from the energy balance in Ireland's Greenhouse Gas inventory for 2003 (published by the EPA in 2005) (Environmental Protection Agency 2005), and other Mining and Quarrying from the CSO. Data on waste was obtained from the EPA Waste Database Report for 2005 (Environmental Protection Agency 2006). Data on water supplied, estimates of leakage, consumption and discharges of waste water are required to create a satellite account for water, however, only data on water supplied to domestic homes was available. Emissions to air were calculated from the Greenhouse Gas inventory and dissipative outputs of products to the environment from the EPA Waste Database Report.

Supplementary information

All spreadsheets, datasets and digital information connected to this project can be obtained from the Environmental Protection Agency at: Secure Archive For Environmental Research Data (SAFER) managed by http://erc.epa.ie/safer/resource?id=0de94270-40b9-102b-950d-28616e04c7da

Acknowledgements

This research was funded by the Environmental Protection Agency as part of the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007-2013. The programme is financed by the Irish Government under the National Development Plan 2007-2013. It is administered on behalf of the Department of the Environment, Heritage and Local Government by the Environmental Protection Agency which has the statutory function of coordinating and promoting environmental research. We would like to acknowledge the invaluable support of Dr Shane Colgan and Kevin Woods of the STRIVE team.

References

Aall, C. and Thorse, I., 2005. The use of the ecological footprint in local politics and administration: results and implications from Norway. *Local Environment,* 10 (2), 159 –117.

Aall, K. and Norland, T., 2002. The Ecological Footprint of the City of Oslo – Results and proposals for the use of the Ecological Footprint in Local Environmental Policy. *Prosus*. Oslo, Program for Research and Documentation for a Sustainable Society (Prosus) Centre for Development and Environment. University of Oslo.

Adriaanse, A., Bringezu, S., Hammond, A., Moriguchi, Y., Rodenburg, E., Rogich, D., and Schütz, H., 1997. *Resource Flows: The material basis of industrial economies.* Washington, DC: World Resources Institute.

Barret, J., Frey, S., Paul, A., and Minx, J., 2007. *Towards a low footprint Scotland. Living well, within our ecological limits.* York, Stockholm Environment Institute.

Best, A., Giljum, S., Simmons, C., Blobel, C., Lewis, K., Hammer, M., Cavalieri, S., Lutter, S., and Maguire, C., 2008. *Potential of the Ecological Footprint for monitoring environmental impacts from natural resource use*. Brussels, European Commission, DG Environment.

Bicknell, K., Ball, R., Cullen, R., and Bigsby, H., 1998. New methodology for the ecological footprint with an application to the New Zealand economy. *Ecological Economics,* 27(2), 149–60.

Bringezu, S., 2006. *Materializing Policies for Sustainable Use and Management of Resources*. Wuppertal: Wuppertal Institution.

Bringezu, S., Schütz, H., and Moll, S., 2003. Rationale for and Interpretation of Economy-Wide Materials Flow Analysis and Derived Indicators. *Journal of Industrial Ecology,* **7**(2), 43–64.

Central Statistics Office, 2004. *Statistical Yearbook of Ireland*. Dublin: Central Statistics Office.

Central Statistics Office, 2006. *Supply and Use Tables for the year 2006*. Dublin: Central Statistics Office.

Cerutti, A., Bagliani, M., Beccaro, G., and Bounous, G., 2010. Application of Ecological Footprint Analysis on nectarine production: methodological issues and results from a case study in Italy. *Journal of Cleaner Production,* 18(8), 771–6.

Commission for Environmental Cooperation, 2001. *Understanding and Anticipating Environmental Change in North America. Building Blocks for Better Public Policy.* Montréal: Commission for Environmental Cooperation.

Costanza, R., 2000. The dynamics of the ecological footprint concept. *Ecological Economics* 32(3), 341–334.

Curry, R., 2011. The use of Ecological and Carbon Footprint Analysis in regional policy making: application and insights using the REAP model. *Surveying and Shaping the Carbon Accounting Landscape in Scotland. The 4th International Conference on Carbon Accounting*. S. Roaf. Edinburgh, Heriot Watt University, Scottish Carbon Accounting Group.

Curry, R. and Maguire, C., 2008. Island Limits. A Material Flow Analysis and Ecological Footprint of Ireland. Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007–2013. Dublin, Environmental Protection Agency. 1: 38.

Curry, R. and Maguire, C., 2011. The use of Ecological and Carbon Footprint Analysis in regional policy making: application and insights using the REAP model. *Local Environment,* 16(9), 917–36.

Curry, R., Maguire, C., Simmons, C., and Lewis, K., 2011. The use of Material Flow Analysis and the Ecological Footprint in regional policy making: application and insights from Northern Ireland. *Local Environment,* 16(2), 165–79.

Curry, R., Simmons, C., and McDaid, C., 2004. *Northern Limits. A Resource Flow Analysis and Ecological Footprint of Northern Ireland*. Belfast, Arena.

Daniels, P.L. and Moore, S., 2001. Approaches for Quantifying the Metabolism of Physical Economies: Part I: Methodological Overview. *Journal of Industrial Ecology,* 5(4), 69–93.

Dietz, S. and Neumayer, E., 2007. Weak and strong sustainability in the SEEA: Concepts and measurement. *Ecological Economics,* 61(4), 617–26.

Duchin, F. and Steenge, A., 2007. Mathematical Models in Input-Output Economics. *Rensselae Working Papers in Economics Number 0703*.

Environmental Policy Group, 2006. *First Steps Towards Sustainability. A Sustainable Development Strategy for Northern Ireland*. Belfast: Environmental Policy Group.

Environmental Protection Agency, 2005. *Ireland. National Inventory Report 2005. Greenhouse Gas Emissions 1990 – 2003 Reported to the United Nations Framework Convention on Climate Change (UNFCCC)*. Wexford: Environmental Protection Agency.

Environmental Protection Agency, 2006. *National Waste Report 2005. Data Update*. Wexford: Environmental Protection Agency.

Environmental Protection Agency, 2012. Secure Archive For Environmental Research Data (SAFER). Science, Technology, Research and Innovation for the Environment (STRIVE) Retrieved 9th March 2012, 2012, from http://erc.epa.ie/safer/.

Ewing, B.R., Hawkins, T.R., Wiedmann, T.O., Galli, A., Ertug Ercin, A., Weinzettel, J., and Steen-Olsen, K., 2012. Integrating ecological and water footprint accounting in a multi-regional input-output framework. *Ecological Indicators,* 23(0), 1–8.

Fiala, N., 2008. Measuring sustainability: Why the ecological footprint is bad economics and bad environmental science. *Ecological Economics*, 67(4): 519–25.

Fischer-Kowalski, M. and Hüttler, W., 1998. Society's Metabolism. The Intellectual History of Materials Flow Analysis, Part II, 1970–1998. *Journal of Industrial Ecology,* 2(4), 107–36.

Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., Moriguchi, Y., Schütz, H., Schandl, H., and Weisz, H., 2011. Methodology and Indicators of Economy-wide Material Flow Accounting State of the Art and

Reliability Across Sources. *Journal of Industrial Ecology*: no-no.
Giljum, S., Burger, E., Hinterberger, F., Lutter, S., and Bruckner, M., 2010. A comprehensive set of resource use indicators from the micro to the macro level. *Resources, Conservation and Recycling,* 55(3), 300–8.
Global Footprint Network, 2006. *Ecological Footprint Standards 1.0*. Oakland, Global Footprint Network.
Haberl, H., 1997. Human Appropriation of Net Primary Production as an Environmental Indicator: Implications for Sustainable Development. *Ambio,* 26(3), 143–6.
Hinterberger, F., Giljum, S., and Hammer, M., 2003. Material Flow Accounting and Analysis (MFA). A Valuable Tool for Analyses of Society-Nature Interrelationships. Encyclopaedia of the International Society for Ecological Economics (ISEE). F. Hinterberger. Vienna, Sustainable Europe Research Institute (SERI).
Hoekstra, A., 2010. (Towards) a complete database of peer reviewed articles on environmentally extended input output analysis. (EE IO). 18th International Input-Output Conference, Sydney, Australia.
Hubacek, K. and Giljum, S., 2003. Applying physical input-output analysis to estimate land appropriation (ecological footprints) of international trade activities. *Ecological Economics,* 44(1), 137–51.
Huijbregts, M., Hellweg, S., Frischknecht, R., Hungerbühler, K., and Hendriks, J., 2008. Ecological footprint accounting in the life cycle assessment of products. *Ecological Economics,* 4(4), 679–916.
Humphrey, S., Loh, J., and Goldfinger, S., 2008. *Living Planet Report 2008*. C. Hails. Oakland, WWF.
Jones, P., 2006. The mass balance movement: the definitive reference for resource flows within the UK environmental economy. *Mass Balance UK*. London, Royal Society of Wildlife Trusts: 32.
Kitzes, J., Galli, A., Bagliani, M., Barrett, J., Dige, G., Ede, S., Erb, K., Giljum, S., Haberl, H., Hails, C., Jolia-Ferrier, L., Jungwirth, S., Lenzen, M., Lewis, K., Loh, J., Marchettini, N., Messinger, H., Milne, K., Moles, R., Monfreda, ., Moran, D., Nakano, K., Pyhälä, A., Rees, W., Simmons, C., Wackernagel, M., Wada, Y., Walsh, C., and Wiedmann, T., 2009. A research agenda for improving national Ecological Footprint accounts. *Ecological Economics* 68(7), 1991–2007.
Kytzia, S., Faist, M., and Baccini, P., 2004. Economically extended MFA: a material flow approach for a better understanding of food production chain. *Journal of Cleaner Production,* 12(8-10), 877–89.
Lenzen, M., 2001. Errors in Conventional and Input-Output-based Life-Cycle Inventories. *Journal of Industrial Ecology,* 4(4), 127–48.
Lenzen, M., Dey, C., and Foran, B., 2004. Energy requirements of Sydney households. *Ecological Economics,* 49, 375–99.
Lenzen, M. and Murray, M., 2001. A modified ecological footprint method and its application to Australia. *Ecological Economics,* 37(2): 229–55.
Leontief, W., 1986. *Input-Output Economics*. New York: Oxford University Press.

Levett, R., 1998. Footprinting: A great step forward, but tread carefully – a response to Mathis Wackernagel. *Local Environment*, 3(1), 67–74.

Linstead, C. and Ekins, P., 2001. *Mass Balance UK. Mapping UK Resource and Material Flows*. London: Forum for the Future.

Loh, J. and Goldfinger, S., 2006. *Living Planet Report 2006*. C. Hails. Oakland, Global Footprint Network.

Lutter, S. and Giljum, S., 2008. *Development of a methodology for the assessment of global environmental impacts of traded goods and services. Development of RACER Evaluation Framework*. Vienna, ERA-NET SKEP Project EIPOT (www.eipot.eu).

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*. C. Hutter. Washington DC, World Resources Institute.

Moffat, I., Hanley, N., Allen, S., and Fundingsland, M., 2001. *Sustainable Prosperity: Measuring Resource Efficiency*. London, Department of the Environment, Transport and the Regions. Sustainable Development Unit: 1–60.

Moffatt, I., 2000. Ecological footprints and sustainable development. *Ecological Economics*, 32(3), 359–336.

Moll, S., Bringezu, S., and Schutz, H., 2005. *Resource Use in European Countries*. Wuppertal: Wuppertal Institute for Climate, Environment and Energy.

Monfreda, C., Wackernagel, M., and Deumling, D., 2004. Establishing national natural capital accounts based on detailed Ecological Footprint and biological capacity assessments. *Land Use Policy,* 21(3), 231–46.

Moos, M., Whitfield, J., Johnson, L., and Andrey, J., 2006. Does Design Matter? The Ecological Footprint as a Planning Tool at the Local Level. *Journal of Urban Design,* 11(2), 195–224.

Ness, B., Urbel-Piirsalu, E., Anderberg, S., and Olsson, L., 2007. Categorising tools for sustainability assessment. *Ecological Economics,* 60(3), 498–508.

Nourry, M., 2008. Measuring sustainable development: Some empirical evidence for France from eight alternative indicators. *Ecological Economics,* 67(3), 441–56.

Nye, M. and Rydin, Y., 2008. The contribution of ecological footprinting to planning policy development: using REAP to evaluate policies for sustainable housing construction. *Environment and Planning B: Planning and Design,* 35, 227–47.

O'Leary, E. and Cunningham, D., 2006. *Material Flow Accounts (MFA) – Demonstration for Ireland 2001-EEO/DS-(1/1)*. ERTDI Programme 2000–2006. Wexford: Environmental Protection Agency.

Opschoor, H., 2000. The ecological footprint: measuring rod or metaphor? *Ecological Economics,* 32(3), 363–336.

Organisation for Economic Co-operation and Development, 1991. *Environmental Indicators: A preliminary set*. Paris: Organisation for Economic Co-operation and Development (OECD).

Rees, W., 2000. Eco-footprint analysis: merits and brickbat. *Ecological Economics,*

32(3): 371–4.
Rees, W., Wackernagel, M., and Testemale, P., 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Jersey, New Catalyst Bioregional Series.
Schaefer, F., Luksch, U., Steinbach, N., Cabeça, J., and Hanauer, J., 2006. Ecological Footprint and Biocapacity. The world's ability to regenerate resources and absorb waste in a limited time period. *Working papers and studies* Retrieved ISBN 92-79-02943-6, from http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-AU-06-001/EN/KS-AU-06-001-EN.PDF.
Simmons, C., Lewis, K., and Barrett, J., 2000. Two feet – two approaches: a component-based model of ecological footprinting. *Ecological Economics,* 32(3), 375–80.
Simmons, C., Lewis, K., and Gonzalez, I., 2006. *One Planet Business. Methodology for determining global sectoral material consumption, carbon dioxide emissions and Ecological Footprints*. Oxford: Best Foot Forward.
Singh, R.K., Murty, H.R., Gupta, S.K., and Dikshit, A.K., 2009. An overview of sustainability assessment methodologies. *Ecological Indicators,* 9(2): 189–212.
Singh, R.K., Murty, H.R., Gupta, S.K., and Dikshit, A.K., 2012. An overview of sustainability assessment methodologies. *Ecological Indicators* 15(1): 281–99.
Statistical Office of the European Communities, 2001. *Economy-wide material flow accounts and derived indicators. A methodological guide*. Eurostat: Luxembourg.
Statistical Office of the European Communities, 2006. *Measuring progress towards a more sustainable Europe. Sustainable Development Indicators for the European Union. Data 1990 – 2005*. Brussels, EUROSTAT.
Stefan, G. and Klaus, H., 2004. Alternative Approaches of Physical Input-Output Analysis to Estimate Primary Material Inputs of Production and Consumption Activities. *Economic Systems Research,* 16(3): 301.
Turner, K., Lenzen, M., Wiedmann, T., and Barrett, J., 2007. Examining the global environmental impact of regional consumption activities – Part 1: A technical note on combining input-output and ecological footprint analysis. *Ecological Economics*, 62(1), 37–44.
United Nations, 1992. *The Earth Summit. United Nations Conference on Environment and Development (UNCED). Agenda 21*. Rio de Janeiro: UNCED.
United Nations, 2003. *Integrated Environmental and Economic Accounting*. New York: United Nations: SEEA.
van den Bergh, J. and Verbruggen, H., 1999. Spatial sustainability, trade and indicators: an evaluation of the 'ecological footprint'. *Ecological Economics*, 29, 61–72.
Wackernagel, M., 1998. Footprints: Recent steps and possible traps. The author's reply to Roger Levett's response. *Local Environment*, 3(2), 221–5.
Wackernagel, M., Monfreda, M., Moran, D., Wermer, P., Goldfinger, S., Deumling, D., and Murray, M., 2005. *National Footprint and Biocapacity Accounts 2005: The underlying calculation method*. Oakland: Global Footprint Network.

Wackernagel, M., Onisto, L., Bello, P., Callejas Linares, A., Susana López Falfán, I., Méndez García, J., Isabel Suárez Guerrero, A., and Guadalupe Suárez Guerrero, M., 1999. National natural capital accounting with the ecological footprint concept. *Ecological Economics,* 29(3), 375–90.

Walsh, C., McLoone, A., O'Regan, B., Moles, R., and Curry, R., 2006. The application of the ecological footprint in two Irish urban areas: Limerick and Belfast. *Irish Geography,* 39(1), 1–21.

Weisz, H., Krausmann, F., Amann, C., Eisenmenger, N., Erb, K., Hubacek, K., and Fischer-Kowalski, M., 2006. The physical economy of the European Union: Cross-country comparison and determinants of material consumption. *Ecological Economics,* 58(4), 676–98.

Weisz, H., Krausmann, F., Eisenmenger, N., Schütz, H., Haas, W., and Schaffartzik, A., 2007. *Economy-wide Material Flow Accounting 'A compilation guide'*. Brussels: Eurostat and the European Commission.

Weterings, R., Opschoor, J., and Opschoor, J., 1994. *Towards environmental performance indicators based on the notion of environmental space: report to the Advisory Council for Research on Nature and Environment, the Netherlands* Rijswijk, Advisory Council for Research on Nature and Environment, the Netherlands.

Wiedmann, T. and Barrett, J., 2010. A Review of the Ecological Footprint Indicator – Perceptions and Methods. *Sustainability,* 6(2): 1645–93.

Wier, M. and Hasler, B., 1999. Accounting for nitrogen in Denmark – a structural decomposition analysis. *Ecological Economics* 30(2), 317–31.

World Commission on Environment and Development, 1987. *Our Common Future. The report of the World Commission on Environment and Development*. Oxford: World Commission on Environment and Development.

WWF-Cymru, 2005. *Reducing Wales' Ecological Footprint*. Cardiff, WWF-Cymru.