

Review and Application of the Ecological Footprint: A Case Study of Agricultural Systems in Scotland

**A dissertation conducted for the degree of
Master of Science**

**Naeeda Crishna
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Introduction

In order for humanity to proceed in the direction of sustainable development, accurate indicators for sustainability are essential to monitor progress and to indicate where improvements need to be made. Like the concept of sustainability, indicators for sustainable development are difficult to define and are therefore fated to undergoing considerable debate no matter how many variables they cover. The Ecological Footprint is one such indicator which from its conception has seen considerable criticism and has received equally vociferous support. This dissertation aims to contribute to the discussion on the Ecological Footprint, and to assess its application by using it to measure the environmental impacts associated with agriculture in Scotland.

This dissertation is laid out in the 'Research Paper' style format and presents two research papers styled in the format of a target journal. The first paper conducts a review of the literature surrounding the Ecological Footprint and presents the three main approaches to applying this indicator. The target journal chosen for this paper is *Ecological Economics* as this journal has followed the progress of the Ecological Footprint since its conception, and most of the debate on this indicator has been published here. The second paper is an application paper which sets presents the results of using the Ecological Footprint to measure the overall ecological impact of farming in Scotland. This paper is styled in the format of target journal *Agriculture, Ecosystems and Environment* as this journal has published a large amount of literature on farming indicators in the past, and appeals to an audience from an agri-environmental background. The third paper to this dissertation is the Discussion paper which critically evaluates the results of the research and identifies future areas of work.

Full results, details of the data used and the procedure for the model used for the Ecological Footprint calculations are presented in Appendices 1- 3. Journal styles of both journals are laid out in Appendices 4 and 5.

SURVEY

A Critical Evaluation of Ecological Footprint Analysis

Naeeda Crishna*

**Center for the study of Environmental Change and Sustainability, University of Edinburgh, King's Buildings,
West Mains Road, Edinburgh EH9 3JN*

Abstract

The aim of this paper is to review a widely known indicator, the Ecological Footprint, by assessing its strengths and weaknesses and providing an overview of the main approaches to applying it. Developed on a strong sustainability perspective, the Ecological Footprint measures consumption of a population and converts this into corresponding land area in order to provide an idea of the sustainability of the population. Strengths of the footprint include that it has been identified as a powerful communication tool which is able to capture ecological impact accurately. Limitations include that it excludes some environmental variables, and that social considerations are not taken into account. The three main approaches to Ecological Footprint analysis are the compound approach, the component approach and footprint calculations using Input-Output tables. The compound approach is seen to work well at a national scale, though there are certain methodological issues identified with the use of the equivalence and yield factors. This approach is seen to cause problems at sub-national level footprint calculations. The components approach is well suited to local level analyses as it evaluates different components of consumption separately. This method, however, is based on Life Cycle Analysis (LCA) data and hence data availability poses a problem. Footprint calculations using Input-Output tables are based on an LCA perspective but use nationally constructed statistical tables to solve the data availability problem. The main finding is that there is a lack of transparency in the published literature on the footprint. However, overall the Ecological Footprint is based on a strong idea, and works well as an indicator of ecological impact which communicates the idea of sustainability to a wider audience.

Keywords: ecological footprint, compound calculations, component calculations, input-output analysis

Word count: 7000 words

Target Journal: Ecological Economics

1. Introduction

In order to progress towards a sustainable future it is important to understand what sustainability means and how it can be measured (Wackernagel and Yount, 1998). Out of the various indicators that have arisen over the recent past which measure sustainable development, Ecological Footprint Analysis (EFA) is widely known. Originally developed in 1996 by Wackernagel and Rees, EFA estimates resource consumption and waste assimilation requirements of a defined population in terms of a corresponding productive land area (Wackernagel and Rees, 1996). Different methodologies for EFA have developed over the last decade through published literature and currently there are three main approaches that are practiced by different academics: the compound approach, the component approach, and EFA using Input-Output Analysis (IOA).

These three approaches have been used in different ways, and applied at different scales. The aim of this paper is to review the development of the Ecological Footprint by assessing the three approaches underlining their individual strengths, weaknesses and examples of their application and use. The review begins by providing a basic understanding to EFA and discussing the underlying concept of strong sustainability in Section 2. It then proceeds to discuss generic strengths and weaknesses of EFA identified in published literature in Section 3. Section 4 provides a comprehensive understanding of the three main EFA approaches and provides a typology of the development of EFA over the last decade. Section 5 completes the review by providing a concise and integrative conclusion.

2. Understanding Ecological Footprint Analysis – Concepts and Assumptions

EFA has been described by authors as the ‘most comprehensive attempt at measuring humanity’s impact’ (Wackernagel and Yount, 2000). It is a biophysical accounting measure

that compares human use of nature with nature's ability to produce resources and regenerate. Basic concepts underlying EFA are those of strong sustainability and that using land to measure consumption provides an accurate idea of sustainability.

EFA has been defined as the land area that is required to produce all the goods and services required by a population and hence how much land is required to support a given number of people (Wackernagel *et al.*, 2002). Authors believe that comparing this figure, in the case of a country, to actual land area within political boundaries, makes it relatively simple to distinguish whether a country is progressing sustainably or not. When referring to the global population, using more resources than is available demonstrates 'liquidation' of the planet's natural capital and points to an unsustainable rate of consumption by humanity (Chambers *et al.*, 2000). Linking the depletion of natural capital with unsustainable progress is the central pillar of the EFA concept and it is what links this indicator to strong sustainability. EFA was originally formulated on a strong sustainability perspective as original practitioners of EFA¹ believed that sustainability requires living within the earth's regenerative capacity. Strong sustainability is rooted in the idea that natural capital cannot be substituted by man made capital, and rejects the idea that technology can make up for the loss of ecological reserves. Strong sustainability emphasizes maintaining natural capital, and is essential as an underlying concept of EFA.

EFA is closely related to the ecological concept of 'carrying capacity' and was initially referred to as 'appropriated carrying capacity' (Wackernagel and Yount, 2000). Where carrying capacity measures how many species a particular land area can support, EFA turns this around and measures how much land area is required to support a particular population. Unlike carrying capacity, EFA takes account of all the biophysical impacts of a population regardless of where they occur. EFA was developed as an area based measure as this reflects the fact that most life supporting activities are dependant on land surfaces (Monfreda *et al.*, 2004). It not only recognizes direct uses of land in terms of area for roads, cities and

¹ Wackernagel and Rees (1996); Wackernagel and Yount (1998); Wackernagel and Yount (2000) and Chambers *et al.* (2000)

agriculture, but also recognizes the indirect uses of land embodied in all products (McDonald and Patterson, 2004). Using land as the basic unit of EFA makes it a descriptive and easily visualized indicator that measures the ecological cost (in terms of land) of providing goods and services to a population (Wackernagel *et al.*, 2005). EFA uses six different land types to demonstrate consumption and these are converted to a common numeraire, the global hectare, using equivalence and yield factors (Wackernagel *et al.*, 2005; GFN, 2006a). Global hectares are hectares normalized to have world average productivity of all biologically productive land and water in any one year.

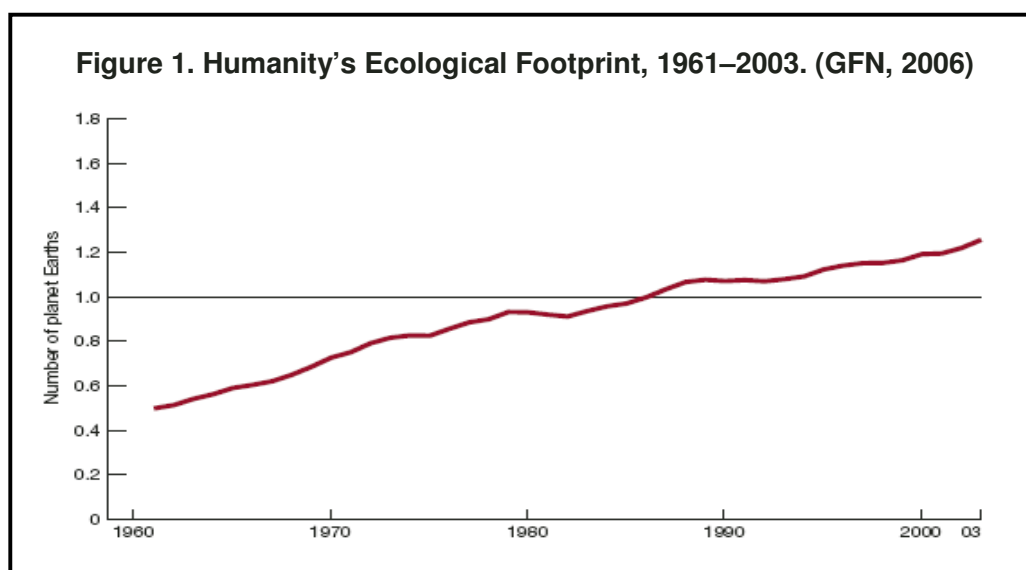
The EFA concept assumes two things. First, that all the resources consumed and wastes generated by a population can be estimated comprehensively and second, that these resource and waste flows can be accurately converted into bioproductive areas of land required to produce these functions (Chambers *et al.*, 2000). It is in the second assumption that EFA methodologies have faced the most criticism and attack as demonstrated in Section 3. An in depth discussion on the three main EFA methods, the compound approach, the component approach and EFA using Input-Output tables, is provided in Section 4.

3. Strengths and Weaknesses of the Ecological Footprint concept

This section provides a brief overview of the main strengths and weaknesses of EFA as an indicator of sustainable development by reviewing some of the main arguments from the proponents, opponents and applications of EFA in published literature.

There have been many critical assessments of EFA as an indicator, some questioning its use in policy making and sustainability (Moffat, 2000; Moffat et al, 2001), some in favor of the broader applications of EFA (Fergusson, 1999; Monfreda *et al.*, 2004; Wackernagel et al 2002) and some exploring different implications of the use of EFA (Constanza, 2000; Deutsch, 2000; Rapport, 2000).

The Ecological Footprint has been described as both an analytical and indicative tool by authors. Van Vuuren and Smeets (2000) identify that for EFA to work as an indicator it must be relevant to policy makers, analytically sound, measurable and easily communicable to the broader public. WWF's Living Planet Report 2006 outlines the Ecological Footprint of the present human population and is a good example to demonstrate the strengths of EFA as an indicator. It estimates that in 2003 the global Ecological Footprint was 14.1 billion global hectares, or 2.2 global hectares per person. Compared to this the biocapacity of the earth (the amount of bioproductive land available) in 2003 was estimated at 11.2 global hectares, or 1.8 global hectares per person. Hence in 2003 demand exceeded supply by 25%, and it took one year and 3 months to generate all the resources that were used in that year (WWF, 2006). As is easily visible in Figure 1, EFA translates material dependence of human beings on nature and provides an easy to understand, clear picture of this dependence. It is because of this that EFA has been identified as a powerful communication tool with 'the potential to affect behavioral change' (Defra, 2005). The clarity and easily digestible message that it can communicate to the wider public is the greatest advantage of EFA as an indicator for sustainability.



Moffat (2000) identifies other strengths of EFA as a national indicator: the calculation method used for basic compound and component EFA is relatively simple, most of the data required

for EFA at a national level is easily available and detailed EFA calculations account for and include trade flows between countries demonstrating the dependence of a population on imports. Also, as has been demonstrated in recent EFA calculations of regional organizations (see Lenzen *et al.*, 2003, Foran *et al.*, 2005a, Wiedmann and Lenzen, 2006b) EFA can be expanded to include a number of different environmental variables and upstream user effects which authors believe enhance the comprehensiveness and accuracy of results.

Applications of EFA have identified further advantages at the business and organizational level. In their calculation of the EFA of Sydney Water Corporation, Lenzen *et al.* (2003) identified that the main advantage of using the Ecological Footprint for a business was to use it in corporate reporting, in particular its ability to engender a sense of personal responsibility amongst its customers in their use of water. By communicating the results of its pilot Ecological Footprint on a per-household and per-customer-served basis, in addition to the whole-corporation results, Sydney Water Corporation was able to educate and influence its customers, who play a significant role in the company's impact on the environment (Lenzen *et al.*, 2003).

However, some of these 'advantages' have been questioned by authors, and coupled with other doubts raised subsequently, the use of EFA as a sustainability indicator has been criticized (see van den Bergh and Verbruggen, 1999). The biggest limitation of the EFA is that it leaves out many components of ecological demand on nature (Lenzen and Murray, 2003). For instance, while calculating Ecological Footprints only carbon dioxide emissions from energy are considered, other greenhouse gases which have a more damaging effect per unit volume and emissions from other sources like dairy farming, industrial processes, coal seams and waste are not taken into account. Haberl *et al.* (2004) identifies that since acid rain is not included in present EFA accounts, the accounts are insensitive to changes in the emissions of acidifying substances. In calculating the Footprint of individual countries not including some of these components may result in a much smaller Ecological Footprint than if these were included in the analysis. Lack of data on imports has also given rise to considerable debate in relation to the Ecological Footprint. At present traded goods are only considered in terms of

their ‘embodied’ energy and in order to account for this embodied energy current EFA accounts convert quantities of agricultural and manufactured goods into their energy equivalents using the same energy intensities for imports and exports *irrespective* of country of origin. Though proponents of EFA defend that distinguishing between countries of imports is an extremely labour intensive task (Wiedmann *et al.*, 2006) allocating all imports to a country the *same* embodied energy values has the propensity to vastly undermine EFA calculations.

It has also been pointed out (see Van den Bergh and Verbruggen, 1999; Lenzen and Murray, 2003) that since Ecological Footprints do not track land use practice it is possible to achieve a smaller Ecological Footprint through more intensive measures like industrialized agriculture. In response to this claim Fergusson (2001) describes that holistic EFA can in fact distinguish between land use practice if yield factors used in calculations are those taking into account sustainable practices. At present, however, it is seen that most EFA approaches use yield factors based on current land practice and EFA does not distinguish between sustainable and unsustainable land use, hence more intensive land use can potentially result in a smaller Ecological Footprint. This may defeat the purpose of reducing human demand on nature. These issues cast doubt on the comprehensiveness of EFA as a biophysical assessment tool and as a ‘comprehensive, robust’ measure (Wackernagel *et al.*, 2005) of how much of the biosphere’s regenerative capacity is used by the human economy.

Another limitation of EFA as an indicator of sustainability is that it does not include measures of social well being. Sherrington and Moran (2007) criticize EFA on the grounds that it is an ‘expert-led assessment of the nations demand on natural capital’ prioritizing global concerns over local concerns. Using the case of an onshore wind farm in Scotland the study outlines a situation where planners have to weigh up a quantified reduction in the Ecological Footprint through increased renewable energy against the apparently less tangible negative impacts (visual impacts, public disquiet) of wind farms in Scotland. In this case though the Ecological Footprint can indicate whether a population is living within the regions biocapacity it fails to take into account social factors which lower its value as a tool towards drafting more

sustainable policies (Sherrington and Moran, 2007). Though this is a specific case, the argument that EFA does not account for local social factors does hold true. Proponents of EFA describe it as a tool for measuring ‘human demand on the biosphere’ and for testing ‘the ecological implications of policy choices’, but in order for EFA to be an accurate indicator of sustainability it has to take into account social, economic and ecological factors.

Many of the weaknesses described above were aimed specifically at original applications of EFA. Some of these have been subsequently addressed in adaptations to the footprint over the last few years with the advent of the newer component and Input-Output based approaches. An overview of these, provided in the next Section, give an in depth understanding to how EFA can be expanded to consider increased ecological variables.

4. Development of the Ecological footprint methodology

This section discusses the main approaches of EFA practiced today and begins with a description of common elements of EFA approaches, followed by a review of each of the three main approaches. This review discusses strengths, limitations, outcomes and effects of each approach comparing it to other approaches.

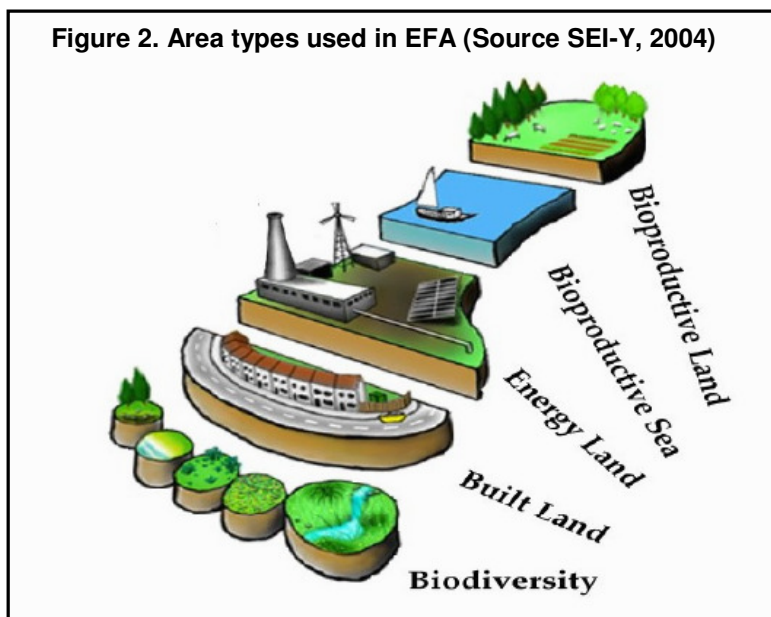
4.1 Common Elements in EFA methodologies

Though the original methodology outlined in Wackernagel and Rees (1996) has been modified and used by many different practitioners² some basic elements of EFA have remained unchanged for most EFA approaches. These include the Footprint components, equivalence factors and yield factors.

² The different approaches are outlined further in this Section.

4.1.1 Footprint components

Ecological Footprint accounts are divided into two parts: calculation of supply or estimation of biocapacity and calculation of demand or Ecological Footprint. The components of demand and supply are then compared to obtain an accurate picture of a population's Ecological Footprint. Biocapacity of a population is estimated by



tracking all 'biologically productive area'³ which includes five categories of land: grazing (pasture) land, cropland, fishing grounds, built up land and forest area (see Figure 2.). These together with land used to absorb carbon dioxide emissions make up the six footprint components, summarized in Table 1.

Table 1. Consumption Components (Wackernagel and Rees, 1996, Monfreda *et al.*, 2004, Wackernagel *et al.*, 2005; Defra, 2005; GFN, 2006a)

Renewable Resources ⁴	
Cropland	Land area with greatest average bioproductivity per hectare.
Area required to produce all food and non food crops	Harvest and area data for major crops are used to calculate area of cropland required to produce a given quantity of crop. Processes that affect land like degradation, erosion etc are not part of the assessment ⁵ .

³ This is defined as 'land and water (both marine and inland) area that supports significant photosynthetic activity and biomass accumulation that can be used by humans' by GFN (2006a).

⁴ This is categorized as two components: bioproductive land space (arable, pasture, forest) and bio productive sea space by Chambers *et al.* (2000)

⁵ GFN (2006a)

Grazing land

Area of permanent pasture for livestock

To calculate this, diet profiles of the mix of crop-based food, fishmeal, animal-based food, cropped grasses, and grazed grasses is created for livestock. The amount of grazing land required is the amount of pasture grass required to meet food requirements of the livestock.

Fishing Grounds

Area required to harvest fish and other marine products

This component only includes areas of marine shelves. Marine areas outside of these are not considered. Catch data are used to estimate demand on fishing grounds and compare this to potential supply estimate.

Forest Area

Area required for harvesting timber products and fuel wood

Productivity of forests is measured using global data. Consumption of round wood and fuel wood are tracked along with processed products like paper, wood pulp and wood panels.

Built Up Land

Area occupied by infrastructure for housing, transport, industrial and hydropower production

Built up area is equal to the same amount of cropland replaced as human settlements are predominantly on fertile land. Hydropower footprint of land inundated by dams and reservoirs are calculated using average ratio of power output to inundated power reservoir area for the world's largest dams. Built up land does not represent biomass that can be used, rather 'destroyed biological capacity'⁶.

Non renewable resources

Carbon land⁷

Area required to sequester carbon dioxide emissions from fossil fuel consumption

Ecological Footprint of fossil fuel consumption calculates area of forest required to assimilate the carbon dioxide emissions. First ocean sequestration is subtracted from overall consumption, then area required to sequester the emissions is calculated using carbon dioxide potential of world average forests. Another method to calculate this component is estimating land area required to produce biomass energy equivalent and this approach gives larger Carbon footprint results. Nuclear energy is

⁶ Gossling et al., 2002

⁷ This category is referred to as fossil fuel land, emissions land and energy land by different authors.

counted as equal to fossil fuel energy. Other than Carbon dioxide no other green house gas emissions are counted in the assessment.

4.1.2 Equivalence Factors and Yield Factors

Ecological Footprint analyses use **equivalence factors** and **yield factors** in their conversion calculations. Consumption data is converted into corresponding land area by using locally obtained yield factors. These are then aggregated using global equivalence factors which adjust the physical areas of land to reflect their bioproductivity.

Equivalence factors⁸ translate a specific land type into a universal unit of biologically productive area, a global hectare. They represent the average potential productivity of any area relative to all bioproductive areas and hence vary with land type. For example, cropland has a larger equivalence factor as compared to pasture because cropland is more productive than pasture. Equivalence factors describe the potential crop yields attainable in an area with an assumed level of inputs such as water and fertilizer, regardless of current management practices or rates of biomass production. The factors thus do not reflect changes in land management due to intensiveness in agriculture etc. Authors argue that using potential productivity as compared to actual productivity makes equivalence factors more robust as changes in productivity over time with differing agricultural practice are not reflected in the Ecological Footprint, and using potential productivity makes time series interpretation simpler (Wackernagel *et al.*, 2005). The equivalence factors used by the Global Footprint Network in their National Footprint Accounts are given in Table 2.

⁸ Equivalence factors are constant for all countries in a given year and are obtained from a spatial model of potential agricultural yields called Global Agro-Ecological Zones (GAEZ) 2000 maintained by the FAO and other international organizations (Monfreda *et al.*, 2004).

Table 2. Equivalence Factors used in National Footprint Accounts 2003 (GFN, 2006a)

Area Type	Equivalence Factor [gha/ha]
Primary Cropland	2.21
Forest	1.34
Grazing Land	0.49
Marine	0.36
Inland Water	2.21
Built	

Yield factors account for differences in production of land area across countries. A hectare of pasture in New Zealand, for example, will produce more meat than a hectare of pasture in Scotland. Yield factors vary by years and according to countries. They are calculated for each bioproductive area and are recalculated every year to reflect the national average. Yield factors are calculated by comparing the production of a specific land type in a nation to world average hectare of the same land type and reflect inherent productivity as well as prevailing technology and management practices. For example a yield factor of 1.5 means that the local yield is 50% higher than world average.

Using yield factors that reflect national averages and equivalence factors that reflect global productivity enables EF estimates of national level studies to be comparable at a global level and yet reflect trends specific to the country in question. However, as pointed out by Wiedmann and Lenzen (2006a) this brings about inconsistencies in the calculation methods used. This is because primary consumption categories like production of agricultural products and mining of minerals are treated at a global level, yet production of secondary products like converting wheat to bread or using minerals in industry are treated at a national level. This means that changing practice at a secondary level will decrease the footprint estimate, but changing practices at a primary level will only affect the footprint total if this change is global rather than national.

4.2. Compound EFA and the National Footprint Accounts

The original Ecological Footprint calculation method developed by Wackernagel and Rees has been significantly improved⁹ and is used today largely by the Global Footprint Network in maintaining the National Footprint Accounts, among others. The method is referred to as *Compound* footprinting, and is based on aggregate national data. The calculation begins with a consumption analysis of biotic resources. These figures are corrected for trade by adding imports and subtracting exports. Energy balance is determined considering locally generated energy and embodied energy from trade goods. The Ecological footprint is then summarized in six ecological categories presented in per capita figures. Because this method is based on data which is available from national and international agencies like the UN and FAO compound footprinting proponents consider their calculations more inclusive and robust (Monfreda *et al.*, 2004). Though the use of data from international bodies does make EFA more uniform and allows comparability between EFA results of different countries, this data is often subject to its own limitations. Wackernagel *et al.* (2005) point out that this data has often been seen to omit or inadequately document some demands on nature like data on the biological impact of water scarcity or pollution, and the impact of waste on bioproductivity. International sources of data are also prone to including information that is useful for national level studies, but which may not be applicable at a more microscopic scale.

4.2.1 Effects of Global EFA calculations

The Global Footprint Network, established in 2003, maintains the National Footprint Accounts which are the central dataset that calculates the Footprint of 150 nations from 1961 to the present and forms the basis for most Ecological Footprint applications. These accounts have been used in WWF's Living Planet Reports and as a starting point for other methods of footprint calculations¹⁰ in various studies. They have also provided the basis for the analysis of global ecological demand and comparison of the relative environmental effects of countries.

⁹ Monfreda *et al.* (2004) outlines the improvements and corrections made to the original EFA methodology from Wackernagel and Rees (1996). Changes include calculation method and data used for equivalence factors, more comprehensive data sources for EFA and changes in the classification of EFA components.

¹⁰ This is described further in this Section.

The National Footprint Accounts for different countries have established two key concepts: ecological overshoot and ecological deficit. The world's population currently uses more than one planet can support and this condition is called ecological overshoot. Comparison of the EFA of different countries has established that some countries are using more resources than they control within their territories, while some countries are using less. This introduces the idea of 'ecological debt'¹¹ which has potentially immense implications for global equity. The Living Planet Report 2006 shows that the Ecological Footprints of higher income countries have increased by 18% between 1992 and 2003 whereas middle and low income countries have recorded little change in their Ecological Footprints, implying that over the last decade activities of the richer countries have had a more damaging effect on the environment than activities of people living in poorer countries. The Living Planet Report 2006 suggests that in the future a shift may be required from the current geopolitical line between developed and developing countries to a new division between ecological creditors and debtors.

Another interesting outcome of the establishment of the National Footprint Accounts is the use of Ecological Footprint with other indicators like the Human Development Index (HDI) and the implications it has had for sustainability and development. The Ecological Footprint Factbook of Africa demonstrates that countries with smaller ecological footprints have also been seen to have very lower HDI¹² values, while countries with high HDI values (which might suggest a greater degree of development) also have larger Ecological Footprints indicating lower level of ecological sustainability (GFN, 2006b). These conclusions suggest that no country is being able to balance social, economic and ecological considerations, and provide a good level of human development as well as a sustainable lifestyle to its citizens; hence no country is pursuing a sustainable path of progress. Though the HDI in itself is in no way an absolute measure of human well being and development and is subject to limitations, the over all results produced by the Global Footprint Network publications are mirrored in

¹¹ GFN (2006a) defines ecological debtors as those countries who use more biocapacity than they control within their own territories. Ecological creditors are defined as those countries that have footprints smaller than their own biocapacity.

¹² GFN (2006b) classifies an HDI of 0.8 as the boundary between medium and high development, and 1.8 global hectares per person as the largest Footprint that could be replicated globally.

other studies¹³. These results might imply that the present concept of human development needs to be altered and in order for countries to be more sustainable, what they perceive to be a necessity for the welfare of their citizens needs to change.

4.2.2 Limitations of the GFN methodology

Though the National Footprint Accounts provide an interesting picture of global ecological demand and forms a basis for inter country comparison of environmental performance, the methodology used in the accounts is subject to certain limitations enumerated below.

The Global Footprint Network identifies 11.2 billion¹⁴ hectares of bioproductive area on the planet, which covers little less than one quarter of total surface area on Earth. The rest of the Earth's surface is not considered in the National Footprint Accounts because though the remaining areas are also biologically active, renewable resources in these areas are not 'concentrated enough to be a significant addition to overall biocapacity' (Wackernagel *et al.*, 2005). Disregarding areas of the Earth's surface may not have a major effect on the global Ecological Footprint, but may well affect footprints at a national and regional level. Lenzen and Murray (2003) use the example of Australia to point out that those areas of the continent which are not considered by GFN are used by various local populations and are essential to an EFA of Australia.

GFN (2006a) provide a summary of a number of activities not considered in the NFA methodology including activities that erode the earth's regenerative capacity like various pollutants, species extinction and release of non degradable substances like PCBs and dioxins. They also make explicit that their methodology tends to underestimate demand in cases of uncertainty. These facets of the compound methodology may not have a significant effect if the approach is to only be used for inter country and global comparison purposes. In cases where the method is to be used for analysis of a region in order to formulate policy or for an

¹³ NEF (2006) has developed the Happy Planet Index which is an alternative development measure based on life expectancy, life satisfaction and EFA. The results show countries with higher life expectancy also have larger Ecological Footprints and vice versa.

¹⁴ This is broken up into: 2.3 billion hectares of fisheries, 1.5 billion hectares of cropland, 3.5 billion hectares of grazing land, 3.6 billion hectares of forest and 0.2 billion hectares of built up land (Wackernagel *et al.*, 2005).

institute in order to track the effects of their activity on the environment, the fact that it does not provide a complete picture of human demand can have a significant effect on the overall result.

4.3 Component EFA: Measuring activities

The component based approach, practiced largely by Best Foot Forward in UK based studies (Defra, 2005), identifies all individual items that a given population consumes and then assesses the Ecological Footprint of each component using life cycle data that tracks resource requirements of a product from extraction to disposal. The overall accuracy of the final result depends on the completeness of the component list as well as on the reliability of the life cycle assessment (LCA) of each.

Defra (2005) outlines the main approach in UK studies, largely carried out by Best Foot Forward over the last seven years. Typically over twenty components are considered for regional organizations or populations, though some of these may be omitted if irrelevant. Footprints are calculated for each of the considered components in order to analyze the following six activities:

- consumption of direct energy
- transport use both passenger and personal
- consumption of food and drink
- consumption of water
- consumption of goods and production of waste, and
- accommodating building and infrastructure

The main advantage that has been seen of this approach is that unlike the compound approach, it includes a detailed account of each component and activity. The component approach gives a disaggregated Ecological Footprint with individual activities of a population analyzed on a smaller scale, and this might suggest it has better use in policy making than other approaches.

Numerous studies¹⁵ have used an amalgamation of both component and compound methods, involving the use of the component method that is calibrated against a compound Ecological Footprint assessment. Best Foot Forward's 'Stepwise' methodology is a component based approach which re-analyses National Footprint Account results. The methodology combines resource consumption, life cycle, and trade data to calculate a range of smaller and more detailed Ecological footprint components. In their Ecological Footprint assessment of Scotland, the National Footprint account of the UK is disaggregated into components and this is compared to an analysis of Scotland's consumption data. The result is a more detailed picture of each of the attributes of the Ecological Footprint. For example, in calculating the direct energy footprint the National Footprint Account gives all energy consumption of the UK as a single per capita figure whereas the Stepwise approach breaks this total down into direct energy for domestic users, services etc. (Best Foot Forward, 2004, Wackernagel *et al.*, 2005). The results of the Stepwise approach highlight the contribution of individual activities to the overall Ecological Footprint, and this could be potentially useful for policymakers and local authorities. The component approach has also been applied to businesses with several advantages of this approach for business noted by authors. Chambers and Lewis (2001) calculated the Ecological Footprint of two businesses, Anglian Water Services and Best Foot Forward and have identified some of these advantages in Box 1.

Box 1. Advantages of component-based EFA (Chambers and Lewis, 2001)

- the single index provides for ease of communication and understanding;
- a variety of goods, activities and services can readily be assessed and compared;
- a link can easily be made between local and global consumption;
- the relationship between different impacts can be explored;
- values are based on ecological realities rather than arbitrary weightings

¹⁵ Defra (2005) classifies the different component methodologies used in 17 EFA studies in the UK: approaches based on locally collected data such as the EcoIndex approach (BFF, 2000) and approaches based on disaggregation of the National Footprint Accounts such as the Stepwise approach (BFF,2004).

The main limitation of the component method is data availability and accuracy. Largely based on life-cycle analysis (LCA) data the methodology adopts all the weaknesses and limitations embodied in life cycle analysis including identification of the system boundary, double counting of impacts and differences in methodology. Defra (2005) identifies that for component EFA studies in the UK, the Goods and Waste footprint is the least transparent and conversion factors used vary widely between studies due to problems with data. LCA data is also not always available and LCA results have been seen to vary widely producing erratic EFA results. These factors make the component method extremely labor intensive in terms of data collection and prone to widely varying totals.

4.4 Footprinting with Input-Output Analysis

Originally developed in the 1930's by Wassily Leontief, Input-Output Analysis is a well known and used economic tool which can be used to study how various sectors of a regional or national economy are related. Though Input-Output tables are based on economic transactions expressed in monetary terms, biophysical effects of economic activity can also be analyzed through these. Environmental extended Input-Output analysis assigns resource flows and environmental impacts to categories of final consumption. Bicknell et al (1998) originally presented modifying EFA using Input-Output tables on an analysis of the Ecological Footprint of New Zealand. Their method was further developed by Ferng (2001), Lenzen and Murray (2001) and McDonald and Patterson (2004). Recent work combining EFA and Input-Output analyses (IOA) include Lenzen *et al.* (2003), Wiedmann and Barrett (2005), Wiedmann *et al.* (2006) and Turner *et al.* (2007).

McDonald and Patterson (2004) describe the major strengths of using Input-Output based methodology for EFA as:

- It provides a formal structure for Ecological Footprint calculations;
- It permits regional level footprint estimates to be generated; and
- It makes explicit interregional appropriation of biologically productive land.

The strength of this method over both other EFA approaches is that it is based on national Input-Output statistics which are routinely constructed by statistical agencies. This avoids the intensive secondary data collection process that has been seen to undermine other EFA approaches. IOA based EFA approaches also introduce a new facet to EFA: analysis of upstream production processes which ultimately includes all production layers into the EFA of a population. Like LCA this method also estimates the effects of all steps in the production of an item, but unlike LCA this method does not have the problem of identifying a system boundary as the national economy forms the boundary. This is demonstrated specifically in the more recent generations of this method including the ISA branch of approaches with Lenzen and Murray 2001, Lenzen and Murray 2003 and the SEI-Y branch of approaches with Wiedmann *et al.* (2006), Wiedmann and Lenzen (2006b) and Turner *et al.*, (2007).

4.4.1 The ISA approach

Lenzen and Murray (2001) and Lenzen *et al.* (2003) introduce a modified Ecological Footprint calculation using IOA that has been developed at the Integrated Sustainability Analysis group, in the University of Sydney, to calculate regional Ecological Footprints, which are decomposed into production layers and structural paths so that all direct and indirect land uses can be included. Their approach is based on actual land condition that gives a better understanding of the regional activity on ecosystem processes as compared to world average bioproductivity as used by the compound EFA approach. They measure land condition by classifying land according to land cover disturbance. This particular method also addresses the earlier mentioned limitation of the National Footprint Accounts by including all areas of land into EFA. A further facet of this approach is that it introduces another category of land to footprint components called 'emissions land'. This category includes emissions of greenhouse gases other than carbon dioxide and other sources of these gases. Though this approach does address some of the issues of other EFA approaches it has not as yet been applied in the same scale as the compound and component approaches and hence what the effects this calculation method would have on national and global EFA results cannot be identified.

4.4.2 The SEI-Y Approach

Another EFA approach based on IOA developed in the UK has been by authors at the Stockholm Environment Institute at York (SEI-Y). SEI-Y has recently developed the Resource and Energy Analysis Program (REAP)¹⁶ – an integrated resource-environment modeling tool based on policy scenarios which has been applied to local governments in the UK. This tool assesses material flows through the UK economy in terms of their environmental impacts and the underlying methodology has been developed and described in Wiedmann *et al.* (2004), Wiedmann and Barrett (2005) and Wiedmann *et al.* (2006). This methodology, like the Stepwise method, uses the National Footprint Accounts as a starting point and disaggregates them by economic sector, final demand category and sub-national area or socio-economic group and authors claim results produced are comparable among other approaches. The approach, which is based on Supply Use Tables, is outlined in Box 1. Supply Use tables are used to construct symmetrical national Input-Output tables and represent a complete picture of the UK economy showing all inputs (domestically produced goods and imports) and all outputs (domestic final consumption and exports) in monetary terms.

Box 2. Calculation Method of the REAP approach

(as described in Weidmann *et al.*, 2006; Weidmann and Barrett, 2005)

1. associate Ecological Footprint of production and imports with industrial sectors
2. update supply matrix (76x76)
3. prepare combined use matrix (76x76) in basic prices
4. calculate direct and indirect requirement matrix
5. calculate direct and indirect intensity vectors
6. calculate the Ecological Footprints of final demand categories
7. disaggregate final demand categories

¹⁶The REAP tool has been developed as a computer based support tool for local authorities to measure and analyze their environmental impact by WWF and has been used in several local authorities in the UK as part of the Ecological Budget UK Project (Wiedmann and Barrett, 2005; WWF Scotland, 2007).

The most significant methodological difference between this approach and the National Footprint Account approach is the calculation of energy used to provide goods and services. Where the National Footprint Accounts base embodied energy on life cycle data, this approach uses Input-Output analysis directly for the use of energy by economic sector, negating the use of life cycle analysis data for UK products (DEFRA, 2005). This approach is akin to the component approach in that it allows the clustering of detailed consumption categories to policy areas such as food, energy, housing etc which increases its relevance for policymaking especially at a local level. However, because it adopts the National Footprint Accounts as a starting point, this approach assumes that all imported goods are produced with world average carbon dioxide intensities. Proponents of this approach acknowledge this limitation and suggest that building up of a multi regional input-output model in the future could address this issue (Wiedmann *et al.*, 2006).

Another software tool has also been developed by ISA and SEI-Y together which incorporates the Ecological Footprint as an indicator for businesses after calculating the business' Triple Bottom Line accounts. Bottomline³ uses an organization's financial accounts and on site data as input to produce Ecological Footprints that can be decomposed by production layer and which facilitates analysis of structural paths. The Ecological Footprints calculated by this tool enable businesses to delineate responsibility for impacts to be shared by all agents along a supply chain (Wiedmann and Lenzen, 2006). This tool is based largely on the ISA method though it does not adopt the use of the disturbed land classification and the inclusion of all land into calculations.

4.4.3 Limitations of EFA with IOA

Bicknell et al (1998), McDonald and Patterson (2004), Defra (2005) and Wiedmann *et al.* (2006) enumerate various limitations of using Input Output Analysis in Ecological Footprint calculations as given in Box 2.

Box 3. Limitations of using Input-Output Analysis in Ecological Footprint calculations

- Input-Output analysis is based on the **assumption of homogeneity** that is each industry produces a single product and all output uses the same processes and technology. This does not always occur in reality as industries are often involved in 'joint production', for example, a dairy farm may use land to produce not only milk but also lesser amounts of beef or horticultural product.
- Another disadvantage of using Input-Output analysis is that, being primarily an economic tool, IOA is based on the assumption that **expenditure is a good indicator of consumption**. This means that if there is unpaid activity in the economy, EFA results of lifestyles and socio economic groups could be distorted.
- Input-output analysis also assumes linear production functions, which implies that inputs must be used in fixed proportions and excludes the possibility of economies or diseconomies of scale. This means that using Input-Output Analysis is useful for measuring current consumption, but the transaction tables and their resulting multipliers **cannot be used as a forecasting tool**.

Footprint calculations based on IOA address some weaknesses of the compound footprinting approaches. Input-Output based Ecological Footprints have been seen to work on a local scale, for regional bodies and companies and for taking into account second and third degree effects of activity. However IOA is a relatively complex econometrics technique which tends to complicate EFA calculations and this takes away from the generic strength of EFA, which is that it is based on relatively simple and easy to implement calculations. This lessens the chances of this approach being easily adopted on a widespread local scale. However IOA based EFA has inspired the development software tools, like REAP and Bottomline³, which may address this issue in the future.

5. Conclusion

Throughout the literature review it has been identified that there is a general lack of transparency in the literature on the specific information relating to calculation methods involved in EFA. The general trend of most published articles is to compare EFA to other indicators, to critique the use of Footprinting at different levels and to present EFA of different populations and organizations. Though it is evident that there are different schools of practitioners who have formulated and currently practice the different approaches to EFA, there is a lack of transparency among these schools especially the practitioners of the component method. The purpose for not specifying calculations may be because of their length and degree of technical content; however, this lack of clarity among practitioners may be the cause for the wide range of differing assumptions and methods¹⁷ that have developed in EFA literature over the last decade.

The Ecological Footprint has come along way from the original idea outlined in 'Our Ecological Footprint' in 1996. Ecological Footprints have been calculated for products and businesses, local authorities and national governments and Footprint 'calculators' are now routinely displayed on websites in order for users to calculate the size of their individual lifestyles. This paper has attempted to produce a review of the major literature on the Ecological Footprint and present the range of approaches currently practiced. The idea underlying EFA is a strong one. The use of the Ecological Footprint in communicating the idea of environmental limits to the general population, it's potential to bring environmental considerations into policy making and it's widespread popularity over the last decade the Ecological Footprint prove that it is a unique environmental indicator and assessment tool. There are, however, many grey areas in the methodology and literature that have not been addressed and these increase the vulnerability of EFA, especially as it is now being used on a very wide scale.

¹⁷ Van Vuuren and Smeets (2000) analyzed the lack of uniformity among EFA results in Netherlands and found that the main factor for this variation was lack of proper definitions and common assumptions.

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The Sustainability of Scottish Agriculture: An Ecological Footprint Analysis

Naeeda Crishna*

** Center for the study of Environmental Change and Sustainability, University of Edinburgh, King's Buildings, West Mains Road, Edinburgh EH9 3JN*

Abstract

This paper aims to assess the sustainability of farm systems in Scotland using a biophysical accounting measure, the Ecological Footprint. Of the methods currently in practice it was seen that using Input-Output tables to disaggregate national footprint estimates was the best way to get accurate farm level results. The study was carried out in two ways, by evaluating the Ecological Footprint of seven different farm types over five years, and by calculating the Ecological Footprint of farms with higher and lower Net Farm Incomes in order to analyze the link between farm income and environmental impact. Defining the threshold for sustainability as 1 (biocapacity equals footprint), results showed that overall the average farm in Scotland uses a little more than half the biocapacity available to it (0.56-0.62) and hence Scottish farming is currently sustainable. Of the different farm types evaluated it was seen that the only type of farming that is not sustainable is Dairy (1.27), while the rest of the sectors in Scottish Agriculture have low footprints when compared with biocapacity (0.53-0.71). During the assessment, calculations presented that modes of expression (per unit area/per unit output) strongly affect the result of the analysis, and it was further seen that depending on the mode of expression, the Ecological Footprint can be used to measure different variables at farm level. Overall, using this indicator is seen to portray an accurate macro-level picture of the agricultural sector in Scotland and to assess the overall environmental impacts of different farm types.

Keywords: farming indicator, ecological footprint, Scotland, input-output analysis

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1. Introduction

It is important to be able to accurately measure the ecological impact of different types of farming activity so that it can be ascertained what direction future agro-environmental reforms and policy should take. This paper applies the Ecological Footprint (EF), a biophysical accounting tool, to measure the sustainability of farming systems by using Scottish agriculture as a case study. This is done by applying the EF to seven different farm types in Scotland over a period of five years. The case study was carried out in two phases. The first phase evaluated the EF of the 'average farm' in Scotland over five years in order to track changes in ecological impact due to recent agri-environmental reforms. The second phase calculated the EF of farms with higher and lower Net Farm Incomes in order to analyze the link, if any, between farm income and environmental impact. The initial section of this paper sets the context by providing a background to farm indicators, the Ecological Footprint and Scottish agriculture. The second and third sections outline the materials and methodology used. The fourth section discusses and interprets the results of the analysis, and the fifth section concludes.

1.1 Indicators of environmental impact at farm level

Intensification of agri-systems in Europe has led to an increase in production and yields, which have been accompanied by the negative effects of environmental pollution and degradation of land. Increasing awareness of these issues has led to a boost in research into different methods of measuring environmental impact at farm level in order to formulate plans for subsequent action (Thomassen and De Boer, 2005; Van der Werf and Petit, 2002; Van der Werf *et al.*, 2007; Galan *et al.*, 2007). Environmental indicators of farming can be loosely classified into two broad categories: indicators specifically aimed at assessing agricultural practice on farms, and environmental indicators that assess effects of these practices (Van der Werf and Petit, 2002). Indicators that assess adherence to good practice, like Environmental Management for Agriculture, would be an example of the former, whereas indicators assessing nitrates lost to atmosphere would be an example of the latter type. 'Effect' based indicators in

turn could be limited to emissions (Nutrient Input-Output calculations), or they could be based on the entire life of a farming product (such as Life Cycle Analysis). A description of some commonly used indicators is presented in Table 1.

Table 1. Commonly Used Farming Indicators

Indicator	Description
Assessment of Impact	
Input-Output Accounting (Goodlass <i>et al.</i> , 2001)	Calculates difference between inputs and outputs of nutrients of a farm, where surplus is assumed to be 'lost to the environment'.
Life Cycle Analysis (Mc Gregor <i>et al.</i> , 2004)	Tracks the environmental impacts of all stages of production, following the agricultural product from 'cradle to grave'
DIALECTE (Galan <i>et al.</i> , 2007)	Evaluates the impact of a farming system on the environment via simple indicators aggregated to two approaches: farmer's practices and environmental themes.
Assessment of farmer practices	
Indicators of Farm Sustainability (Van der Werf and Petit, 2002)	Evaluates ecological, economic and social sustainability using indicators based on farmer practices and behavior
Environmental Management for Agriculture (Van der Werf <i>et al.</i> , 2007)	Compares farmer practice and site impacts with regulatory compliance and perceived 'Best Practice'.

A review of the literature shows that most studies evaluating environmental indicators of farming have been based on an assessment of one type of farming, either dairy or pig farming (Passel *et al.*, 2006; Basset-Mens *et al.*, 2007; Van der Werf *et al.*, 2007), or a comparison between organic and conventional farms (Halberg *et al.*, 2005). There are few studies that cover the whole agricultural sector, or provide a comparison between cropping and livestock farms. Authors have also identified that difference in the methodology used in research on farming indicators produce varied results, with a lack of comparability among these results leading to a lack of consensus on environmental impacts from particular farm types within one geographical area (Van der Werf *et al.*, 2007). The analysis in this paper, unlike previous work, covers the breadth of the agricultural sector in Scotland and discusses the relative impacts of arable and livestock farms in comparison to each other.

An important factor to consider while using indicators of farming is the mode of expression of impact. This could be in terms of the product (indicator per kg of meat) or in terms of the area of land considered (indicator per unit area), and the choice of which mode is considered strongly affects the result of the study (Van der Werf *et al.*, 2007). Some authors argue that environmental impact should be expressed per unit area so as to take account of carrying capacity of the farming system (De Kroejer *et al.*, 2002), while others stress that environmental impact should be expressed per unit product (Halberg *et al.*, 2005). Van der Werf (2007) compared different environmental assessment methods for farms per unit area and per unit product with varying results, and suggests the need to consider both. In this paper, results have been expressed per unit area and per unit output in order to interpret the value of differently expressed results.

Thomassen and De Boer (2005) state that a ‘relevant’ indicator for farming is one which can provide accurate information about the issue in question and can provide results that are understandable by all the stakeholders involved. The Ecological Footprint (EF) is a composite indicator that measures resource use at farm level by translating consumption of a farm into land area required and presents the results in global hectares (gha); a normalized EF unit which is especially relevant to agricultural systems¹. It is commonly acknowledged that farm production depends largely on man made and natural inputs into the farm, hence using an ecological measure that emphasizes inputs and ecological resource use of a farming system, rather than focusing specifically on practice or effect, can provide interesting results in terms of the sustainability of farm production and the farming system as a whole. Further, one of the biggest strengths of the EF to date has been its ability to communicate the idea of environmental limits to a wider audience (Leighton, 2004; SEI-Y, 2004).

¹ Global hectares (gha) are a standardized EF unit that represent hectares with the potential to produce usable biomass equal to the world’s potential average of that year (Monfreda *et al.*, 2004)

1.2 Ecological Footprint – A short review

The Ecological Footprint (EF) has been used widely by various authors and has been applied at a national (Best Foot Forward, 2004; Wackernagel *et al.*, 2005), regional (Bouazzoui *et al.*, 2007) and organization level (Chambers and Lewis, 2001; Lenzen *et al.*, 2003). Defined as a biophysical accounting tool that measures human consumption and waste assimilation requirements in terms of corresponding land area, the EF was originally developed by Wackernagel and Rees in 1996. The original methodology outlined in Wackernagel and Rees (1996) has seen much debate (van der Burgh and Verbruggen, 1999; Fergusson, 2001), and has been modified by various authors to include different aspects of human resource use (Lenzen and Murray, 2001).

The overall EF is composed of six main components; cropland, pasture, forests, sea, built land and the energy footprint. Energy use is considered in a waste assimilation sense; land required to sequester CO₂ emissions from using fossil fuel energy makes up the energy footprint. These categories are used in two ways: to represent the resource use of a population or the ‘demand’, and to calculate how much biocapacity a population has, or the ‘supply’. Biocapacity is a measure of ‘bioproductive’ land, and is measured by categorizing the land in an area according to the Footprint components (excluding the Fossil Fuel Footprint) and converting it into global hectares. In order to obtain an estimate of whether a population is sustainable, total bioproductive space (in global hectares) is compared with the overall EF (in global hectares).

Comparing the overall biocapacity of a farm with its EF provides a theoretical estimate of whether a farm can sustain itself or not, and how much of its ecological resources a farm is using. In reality however comparing these two does not provide an actual estimate of whether a farm can sustain itself or not as farmland supports the production of primary agricultural products and farms use a variety of products which require other types of land as well. Never the less, comparing these two components does indicate the level of ecological impact of a farm by measuring theoretically how much land a farm requires within or outside its boundaries.

The three main approaches to applying EF today are as follows: the compound approach, the component approach and EF approaches using input-output methodology. The compound approach is used in the calculation of the National Footprint Accounts and is based on aggregate national data which is converted into corresponding land area using local yield factors (Wackernagel *et al.*, 2005). Using the compound approach to measure the EF of farms would provide a total estimate for Scottish Agriculture, which would then have to be disaggregated to obtain an estimate for each farm type. A common criticism of using this approach is that as it is based on global level data and is used primarily for national level studies, obtaining sub national results is often difficult. For example, using the compound approach for Scottish agriculture would calculate estimates using equivalence factors which are based on world average 'potential productivity' (Wackernagel *et al.*, 2005). Hence the results for each farm type would reflect the worldwide trends to a certain extent, rather than trends particular to Scotland.

The component approach is a bottom up approach to EFA that considers different components of human consumption separately using life cycle analysis data (transport, energy, food and drink etc.) and then aggregates these to provide a total estimate (Defra, 2005). The component approach would provide accurate farm level results by calculating estimates for different products used on a farm, but data for all these is not readily available. For example, inputs to a farm include agro-chemicals, feed concentrates and veterinary and medical services, among a host of others. Life Cycle Analysis (LCA) estimates on each of these products is difficult to obtain, and LCA data is also prone to a large range of variation (Monfreda *et al.*, 2004). Further, using this approach may not provide estimates that are comparable to estimates in future studies.

EF approaches using input-output analysis (IOA) are a recent entrant into the EF arena, and provide a way to disaggregate national level footprint estimates into local consumption categories without any distortion to local level results (Bicknel *et al.*, 1998; Lenzen and Murray, 2003; Wiedmann *et al.*, 2006). This method uses input-output tables, which are a

commonly applied economic tool, to disaggregate national estimates at a local level and then converts these into a corresponding land area. IOA based studies are based on the concept of LCA in that they include all the impacts of the supply chain involved in producing resources used by a population. EF using IOA calculates the direct impacts (those produced onsite) and the indirect impacts (those embodied in the products purchased) of a farm system providing a wide picture of environmental impact. This method can be seen to incorporate the advantages of both the earlier methods by producing sub-national farm level results using relatively accurate and easy to obtain data sources, though its disadvantage is that it assumes that expenditure is an accurate indicator of consumption (Bicknell *et al.*, 1999). This method has been applied for EFA in different ways (Bicknell *et al.*, 1998; Lenzen and Murray, 2003; Weidmann *et al.*, 2006) and forms the basis for two different software tools in the UK which evaluate the footprint of local authorities and organizations (Wiedmann and Barrett, 2005; Wiedmann and Lenzen, 2006). An in depth discussion on the model used in this paper, Bottomline³, is provided in the methodology section (Section 3).

The main Ecological Footprint methodologies described above have been criticized for not including certain components of ecological demand on nature, such as greenhouse gas emissions other than carbon dioxide, and emissions from sources other than the use of fossil fuels. National statistics in the UK show that in 2005, methane accounted for 8% of the UK's greenhouse gas emissions and that 37% of this methane was from agricultural sources (Baggot *et al.*, 2007). Methane is emitted as a byproduct of agricultural activity during the management of manure and from animals due to enteric fermentation, and in order to gain an accurate picture of the ecological impact of agriculture it is necessary to account for these emissions. This is particularly true in Scotland where the latest agricultural census reports that the livestock population is over 2 million cows and 7 million sheep (SEERAD, 2007a). Hence, in this paper emissions from methane were included into the EF calculations, though this deviates from the standard EF techniques as defined by GFN (2006).

Using methods that consider the entire supply chain of a product introduces the question of who the responsibility of the chain should be attributed to. In traditional LCA, all the impacts

of the supply chain are attributed to the final product thereby making the final consumer responsible for all these impacts. In other accounting methodologies, such as reporting for greenhouse gas emissions to the Intergovernmental Panel on Climate Change, full producer responsibility is assumed where the country that produces a product is responsible for the emissions from that particular production process. A disadvantage of full producer or consumer responsibility is that it does not allow for both producers and consumers to report their impacts without double counting in the national economy (Lenzen *et al.*, 2006). In reality, as pointed out by Gallego and Lenzen (2005), both consumers and producers are responsible for the EF of a particular product. The methodology used in this paper assumes 'shared responsibility' and allocates half the EF calculated to the farm in question, with the other half being allocated to the rest of the supply chain.

Practical application of the EF has seen a number of variable results due to differences in methods used, and the lack of a standard suite of EF techniques (Defra, 2005). In order to try and avoid this, the method used in this paper is based on Wiedmann *et al.* (2006) which uses the National Footprint Accounts as a starting point, a practice that is becoming common in EF studies so as to allow comparability among results (Best Foot Forward, 2004). Most of the guidelines set out in the Ecological Footprint Standards as defined by the Global Footprint Network Standards Committee (GFN, 2006) have also been followed so as to allow repeatability of the study.

1.3 Current Applications: Ecological Footprint of Agricultural Systems

Ecological Footprint Analysis (EFA) has been applied to agriculture in a few studies, with varied results (Kautsky *et al.*, 1997; Thomassen and De Boer, 2005; Van der Werf *et al.*, 2007). Thomassen and De Boer (2005) identify the weakness of the EF in an assessment of the ecological impacts of dairy farms in the Netherlands. They point out that the EF produces only one indicator (in their case, m²/kg product) as a result and that it is limited in scope as it tracks only land use and carbon emissions. Their application of the EF, however, differed from the

three main approaches to EF outlined above. As demonstrated by Lenzen and Murray (2001) the scope of the EF can be expanded to include all emissions from agricultural activity, or all layers of consumption in the supply chain as demonstrated by Wiedmann *et al.* (2006). Further expressing the indicator in only one mode, per unit livestock, can portray only a limited picture of the overall effect of a farming system as pointed out by Van der Werf *et al.* (2007). In contrast to this application, Kautsky *et al.* (1997) find that using the EF to track the ecosystem support area required for shrimp farming in Caribbean waters is a useful measure of the sustainability of aquaculture, as it portrays a real picture of how much land area outside aquaculture cages is actually required to support this industry.

Van der Werf (2007) finds that the EF is narrow in focus as it only considers three environmental objectives (see Table 2). However, in their case the component based application of the EF only took into consideration direct impacts on the farm. Using EFA based on Input-Output tables would widen the scope of this assessment by including indirect impacts of the farm (Wiedmann *et al.*, 2006), and the environmental objectives would increase.

**Table 2. Environmental Objectives considered by differing methods used for EFA
(adapted from Van der Werf *et al.*, 2007)**

Environmental objectives	Methods			
	LCA	EF (Thomassen and De Boer, 2005)	EF (Van der Werf <i>et al.</i> , 2007)	EF (Wiedmann <i>et al.</i> , 2006)
Input related				
Use of non-renewable energy	✓		✓	✓
Land use	✓	✓	✓	✓
Water use				✓
N fertilizer use				✓
P fertilizer use				✓
Pesticide use				✓
Emission related				
Emission of greenhouse gases	✓	✓	✓	✓
Emission of acidifying gases	✓			
Emission of eutrophying substances	✓			
Emissions concerning terrestrial ecotoxicity	✓			

There are some limitations to using the EF to measure the sustainability of farming in Scotland. First, polluting effects like pathogens to water bodies, persistent organic phosphates from pesticide use, nitrates from manure spreading, degradation of land quality due to intensified production are all essential components of ecological impact of a farm system which the EF does not or cannot track. Second, effects of a farm adopting more environmentally friendly practices are not captured by the footprint. For example, due to recent Common Agricultural Policy (CAP) reforms an increasing number of farmers in Scotland are adopting the Rural Stewardship Scheme, Scottish Forestry Grant Scheme and other agri-environmental schemes (LGP, 2006), which would involve growing more trees, maintaining land in a better condition and encouraging biodiversity and natural habitats. There is no method in the present EF calculations to be able to capture the effects of these, yet the fact that farmers are deliberately choosing to adopt more environmentally friendly practice does indicate that future development could be more sustainable. Overall, however, the EF provides for an integrated analysis of a farm system and produces the result in a single numeraire, and even with its limitations, it can be expanded to incorporate a wide range of environmental variables as demonstrated in Table 2.

1.4 Agriculture in Scotland

Responsible for 1.4% of Scottish Gross Domestic Product in 2000, Scottish agriculture employs 8% of the rural workforce and is more dependant on livestock production (UADAF, 2001). Agricultural land in Scotland covers 75% of the total land area, with 83% of this being classified as 'Less Favoured' due to the poor quality of land in terms of soil, climate and remoteness (WWF, 2004). Scottish farmland support a large variety of different birds, and most Scottish habitats are semi-natural rather than natural. Intensive farming activity associated with increased pesticide and fertilizer use has resulted in the decline in farmland bird species over the last two decades (Benton *et al.*, 2002). However, 45% of farming in Scotland is in upland areas where the system of farming is extensive and depends more on

semi-natural vegetation and natural cycling of nutrients, which could be considered more 'environment friendly' (WWF, 2004).

There has been a great deal of research into the effects of European farming in general, but studies specific to different countries are few and far between. Though the overall EF of Scotland has been calculated twice in the last five years (Best Foot Forward, 2004; SEI-Y, 2007), there has been no work done on the overall environmental effects of agriculture, or farm types, in Scotland. Hence, so far there has been no way of quantifying which farm types have a larger impact on the environment and which are more efficient in their use of natural resources. This study aims to fill the lacuna in the literature by presenting macro-level results for agriculture in Scotland, and by comparing different farm types within one sector. It also aims to add to the literature on the EF by assessing the overall use of the EF in agriculture.

2. Data

All the data in this study was obtained from national statistics publications (SEERAD, 2007a; 2007b) as these are a comprehensive, official source of information that allow the comparability of results and provide an accurate macro-level picture of Scottish farming.

2.1 Revenue and Expenditure Data

Revenue and expenditure data of farms were obtained from the 'Farm Incomes in Scotland' and 'Economic Report on Scottish Agriculture' publications (SEERAD, 2007a; 2007b). These publications include statistical data collected through an annual financial survey of farms (Farm Accounts Survey) collected from over 500 farms around Scotland. Though most of the estimates in this dataset are an average of farms surveyed and may not reflect geographic and climatic differences at an individual farm level, they reflect changes in practice between farm types and for a particular farm type over a period of time.

The assessment of farming in Scotland was based on the average figures of all farms surveyed as presented in the dataset (referred to here onwards as the ‘Average Farm’). The assessment considered agriculture from 2001 to 2005, as this was the most recent data available². The analysis of EF and income was based on figures for higher and lower performing farms as ranked by Net Farm Income (NFI).

Other data sources include ‘Farm Accounts in England’ reports and the ‘Agriculture in the United Kingdom’ publications (Defra, 2007). Data on fuel prices and electricity tariffs were obtained from the Farm Management Handbooks series (SAC, 2006), while disaggregation of the data described in Section 2.2.3 were obtained from the Farm Business Benchmarking dataset (Defra, 2006).

2.2 Classification of Farms

For the sectoral analysis of Scottish agriculture, farms were analyzed according to the official classification method. Farms systems in Scotland are classified³ into eight main types according to proportion of production of different livestock and crops (Table 3). This classification of farms is based on the European Union farm classification system. Though there are other farm types in Scotland than mentioned in Table 3, (for example: pigs and poultry), these contribute little to agriculture in Scotland overall. This study assessed seven of the eight farm types presented in Table 3. Data was unavailable for ‘Lowground Cattle and Sheep’ and hence this category was omitted from the assessment.

² Farm Account Survey data in Scotland is published with the time lag of almost two years and hence data for 2005-06 is published on 2007.

³ Farm classification is based on the relative importance of the various crop and livestock enterprises on each farm assessed in terms of standard gross margin. The method of classifying each farm is to multiply the area of each crop (other than forage) and the average number of each category of livestock by the appropriate standard gross margin, the proportions of the total contributed by the various enterprises determining the type of farm (Scottish Executive, 2005).

Table 3. Definition of farm types assessed in this paper (SEERAD, 2007)

Type	Definition
Specialist Sheep (LFA ⁴)	Farms in the less-favored areas with more than two-thirds of the total standard gross margin coming from standard gross margin coming from sheep.
Specialist Beef (LFA)	Farms in the less-favored areas with more than two-thirds of the total standard gross margin coming from cattle.
Cattle and Sheep (LFA)	Farms in the less-favored areas with more than two-thirds of the total standard gross margin coming from sheep and beef cattle together.
Lowground Cattle and Sheep	Farms NOT in the less-favored areas with more than two-thirds of the total standard gross margin coming from sheep and beef cattle.
Cereals	Farms where more than two-thirds of the total standard gross margin comes from cereals and oilseeds.
General Cropping	Other farms where more than two-thirds of the total standard gross margin comes from all crops.
Dairy	Farms where more than two-thirds of the total standard gross margin comes from dairy cows.
Mixed	Farms where no enterprise contributes more than two-thirds of the total standard gross margin.

3. Methodology

3.1 Model Description - EF Calculations with Bottomline³

In order to calculate the EF of seven different farm types across Scotland, and over 5 years, a model, Bottomline³ (BL³) was used for the EF calculation. The methodology underlying the BL³ model is described in Wiedmann *et al.* (2006), however, an overview of how the estimates are produced is described below.

⁴ Less Favoured Areas (LFAs) are those agricultural areas that are naturally disadvantaged in terms of soil, climate, topography etc. which makes it difficult for farms in these areas to compete at the same level with other farms (SEERAD, 2006).

The BL³ model disaggregates the National Footprint Account of the UK (as maintained by the Global Footprint Network) by economic sector, producing an EF estimate in global hectares. It has been pointed out in numerous studies (Defra, 2005; Wiedmann *et al.*, 2006) that one of the main limitations of the EF is that there is no standardized method of ‘footprinting’ and hence different studies produce varying results. The rationale behind the EF methodology in BL³ is that since it is based on the linkage between two consistent national datasets, the National Footprint Accounts and National Input-Output Tables, a certain degree of standardization and comparability are introduced into results produced. As explained in Wiedmann *et al.*, (2006) the method for BL³ is not a ‘modified’ EF, nor does it aim to ‘upgrade’ National Footprint Account data. Rather it is a way of using this data to produce EF estimates at any spatial scale. However, in using this method, all assumptions and limitations of the National Footprint Account method are adopted in the results produced.

The model calculates the EF of a farm in two steps. The first step calculates the land area required by the farm directly, such as area for crops and livestock and land required to assimilate emissions from transport, electricity and natural gas. This is done from on site impact data of a farm that is entered into the model in terms of kwh of electricity or hectares of land allocated to crops or livestock. This data is then converted into the five EF components in global hectares using the NFA equivalence and yield factors. Data for this step was retrieved from the disaggregation of the Farm Accounts Survey and included fuel use, electricity use, details of methane emissions and land use.

The second step in the BL³ calculations accounts for the indirect impacts of the farm or the land area required to sustain all the goods and services used in a farming system like fertilizers, pesticides, feed, construction activities etc. Using revenue and expenditure data of a farm as input, BL³ allocates these to required sectors of the UK economy using a concordance table. This table allocates the expenditure or revenue item to the economic sector classified under the UK Standard Industrial Classification of Economic Activities 2003. The upstream effects of each of these are then calculated using data from the disaggregation of the National Footprint Accounts.

Some categories of data like fuel use and electricity consumption are entered in both steps. However, the two steps are segregated in such a way that double counting of impacts is avoided. For example, in the first step petrol usage is entered in litres and is used to calculate the impacts associated with actually using the fuel for, say, the haulage of animals. In the second step money spent on buying the same fuel is used to calculate all the impacts associated with the extraction, refining and distribution of the fuel, i.e. indirect impacts of using the fuel.

3.2 Disaggregation of Data and Correcting for Inflation

The Farm Incomes in Scotland reports are published for the purpose of analyzing economic trends in Scottish Agriculture and present expenditure and revenue categories for different farm types. So as to provide an overall picture of Scottish agriculture many of the expenditure categories are grouped together to produce aggregate figures. For example, the 'Miscellaneous' category in the inputs to a farm section of the data, includes expenditure on 'electricity, vehicle tax, fuel use and secretarial costs'. As obtaining the disaggregated figures was not possible due to time constraints, this data was disaggregated by using similar figures for the same farm type presented in other sources of information (Defra, 2006; 2007).

In order to account for the pasture land and crop land components of the EF, hectares of cropland (area of cereals, potatoes and oilseed rape) were subtracted from the overall area of the farm in order to calculate area of pasture land. As area of built land on a farm is negligible compared to these other two components of land use, there was no land kept aside for this category, though BL³ automatically allocates a certain amount to other EF components. Biocapacity of farms was calculated separately, by converting areas of crop and pasture land into global hectares using the conversion factors⁵ used in the BL³ model.

⁵ When converting Cropland from hectares to global hectares the factor used is 5.6, and for Pasture land the factor used is 0.72. These are derived from the equivalence and yield factors used in the NFA and are specific for the UK.

For the trend analysis, it was necessary to correct prices for inflation, as this would better reflect the physical materials used. This was done using the Agricultural Price Indices maintained by Defra, taking the year 2001 as base year.

3.3 Accounting for Methane Emissions

This paper presents EF estimates which have included methane emissions from farming systems in Scotland. However, in doing this we have deviated from the standard footprinting methodologies (GFN, 2006), so to ensure that estimates presented here are comparable with other studies, both the EF with methane and EF without methane emissions have been presented.

4. Results

This section presents and discusses the results of the estimates calculated for agriculture in Scotland. The section begins with an analysis of the ‘Average Farm’ in Scotland, and then proceeds to a sectoral analysis of different farm types. This is followed by the results linking the EF with farm performance and concludes with a discussion of EF results expressed in different modes.

4.1 Macro-level analysis of Agriculture in Scotland

The analysis of the ‘Average Farm’ in Scotland over the last five years yielded results that have been analyzed to present a macro-level picture of Scottish agriculture (Table 5). Overall it is seen that the footprint of the average farm in Scotland varies between 214-232 gha which is smaller than the average farm size (231 – 290 hectares), and the average bioproductive space a farm occupies (367 – 390 gha). Considering that *theoretically* a farm can sustain itself if the resources it uses aggregate to less than the overall bioproductive area in the farm, the threshold limit for sustainability would be 1. At this limit the resources used to sustainably support the farm would be equal to the land area the farm occupies with world average

biocapacity. EF estimates for Scottish agriculture, compared against the bioproductive space occupied, are all within this threshold limit even with the inclusion of methane emissions (Figure 1). Studying these results it can be concluded that farming in Scotland is sustainable in that overall land required to produce resources used by farms is smaller than the perimeter of the farms themselves. Considering that earlier studies have shown that at a national level Scotland is progressing unsustainably⁶ by using 2.8 times (Best Foot Forward, 2004) or 3 times (SEI-Y, 2007) the ‘fair earthshare’ available, these results that conclude that overall agriculture in Scotland is sustainable as it uses less land than it occupies, have interesting implications for identifying which sectors are contributing most to the national EF total.

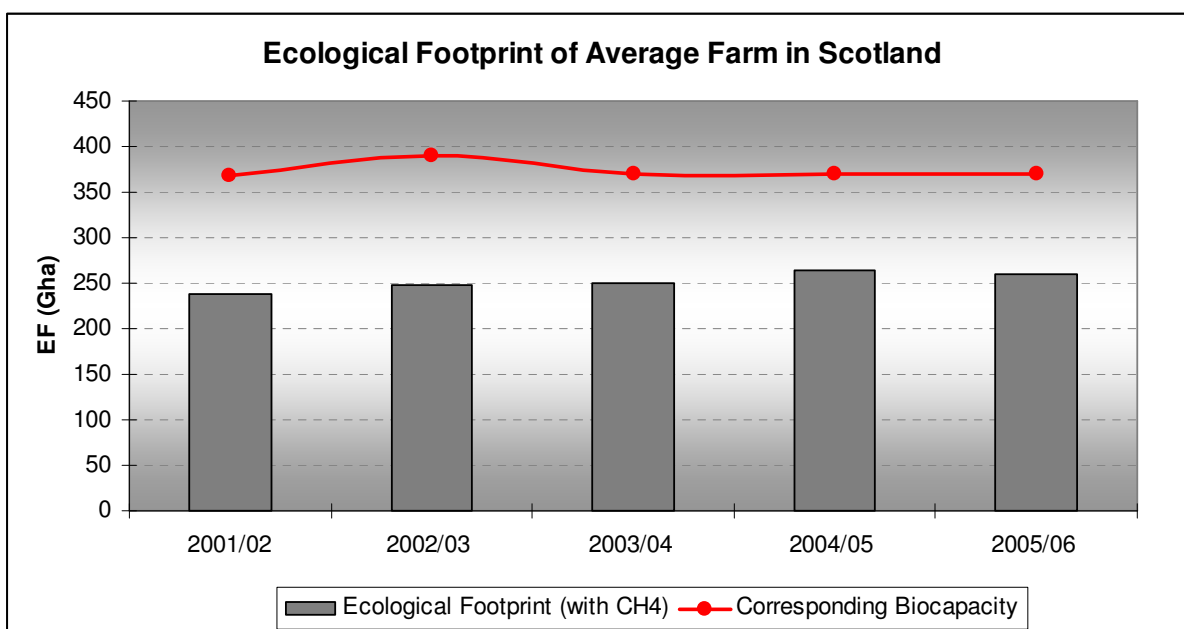


Figure 1. Ecological Footprint (with CH₄): 2001 - 2005

⁶ The difference in both these estimates can be attributed to the methods used for the calculation. Best Foot Forward (2004) use the an integrated component-compound approach, whereas SEI-Y (2007) use the same methodology as outlined in this paper, i.e. Wiedmann *et al.* (2006)

Table 5. Ecological Footprint Results of Average Scottish Farm 2001-2005

	2001/02	2002/03	2003/04	2004/05	2005/06
Ecological Footprint (gha)	214	217	217	232	229
Footprint with CH4 (gha)	238	248	250	264	261
Average size of farm (hectares)	231	290	262	283	290
Bioproductive space (gha)	367	390	370	370	370
Ecological Footprint Breakdown					
Ecological Footprint	214	217	217	232	229
Fossil fuel energy Footprint	19.5	21.4	22.1	22.4	18.7
Nuclear energy Footprint	0.69	0.78	0.84	1.03	1
Crop land Footprint	123	112	112	114	111
Pasture Footprint	69.8	82.3	82.3	94.7	97.6
Built land Footprint	0.12	0.13	0.13	0.07	0.07
Sea Footprint	0.21	0.26	0.26	0.023	0.26
Forest Footprint	0.05	0.05	0.05	0.04	0.06
EF/Biocapacity	0.58	0.56	0.59	0.63	0.62
Footprint with CH4					
Footprint with CH4	238	248	250	264	261
Fossil fuel energy Footprint	43.5	52.8	54.3	54.5	51
Nuclear energy Footprint	0.69	0.78	0.84	1.03	1
Crop land Footprint	123	112	112	114	111
Pasture Footprint	69.8	82.3	82.3	94.7	97.6
Built land Footprint	0.12	0.13	0.13	0.07	0.07
Sea Footprint	0.21	0.26	0.26	0.023	0.26
Forest Footprint	0.05	0.05	0.05	0.04	0.06
EF(CH4)/Biocapacity	0.65	0.64	0.68	0.71	0.70

Though the EF estimate indicates that the average farm in Scotland is sustainable, this aggregated figure masks many smaller variations. For example, the average Scottish farm in the lowland areas are more intensively farmed due to conducive climate and soils, whereas farms in the upland or LFA areas, are largely extensive due to harsh weather, poor soils and hilly topography (SEERAD, 2007a). Upland farming has supported more traditional methods of ‘crofting’ which have always been associated with diverse bird life and maintenance of land in a semi-natural state (WWF, 2004). The percentage of land use in Scotland that is associated

with extensive farming is much larger than those associated with more intensive types of farming like arable and dairy farms as can be confirmed by the EF results which show that the pasture footprint component is by far the largest contributing component of the EF estimates (Figure 2). However, the more intensive farm systems contribute more to overall agriculture in terms of value of output. As the aggregate data used is representative of the division of land use in Scotland, the aggregate EF is a smaller figure than would be if the aggregate data was representative of division between contributions to overall production.

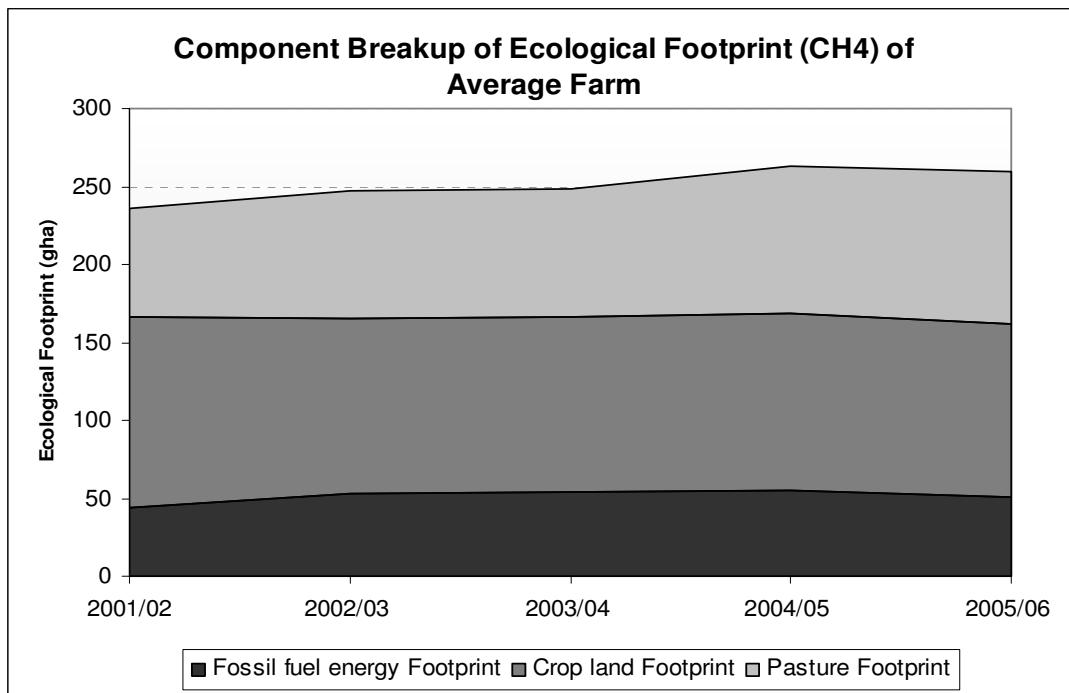


Figure 2. Ecological Footprint Disaggregated

When analyzing the trend in EF estimates over five years, though there is no conclusive trend observed, there is a slight increase in EF estimates till 2004 and then a decline in 2005, corresponding to the establishment of the Single Farm Payment in 2005. CAP reforms of 2004 were expected to decrease intensified farming and to increase farm diversification and sustainable practices by decoupling subsidies from production (Schmid and Sinabell, 2007). Special studies on enterprise costs of cattle and sheep farms in Scotland present that up to the year before the reforms, there was an increase in cattle and sheep numbers and farm production because of the impending reforms with farmers aiming to be at in the strongest

position during the assessment of the Single Farm Payments (LGP, 2004; 2005). The studies state that the effects of decoupling were expected to begin from 2005 onwards.

4.2 Sectoral Analysis of Scottish Agriculture

The sectoral analysis of Scottish agriculture showed that when considering footprints without methane emissions, EF estimates for all the farm types (Table 6) are seen to have a value below 1. However, when methane emissions are included in the assessment the EF values for all farm types increase. This increase is particularly relevant for Dairy farms which cross the threshold value and can be seen to consume more resources than the biocapacity on the farm, if methane emissions are included in the assessment. These results demonstrate that including methane emissions is particularly important when assessing the effects of an agricultural system.

When analyzing Footprints of different farm types in comparison with each other, it is observed that Dairy farms have the highest footprints and Specialist Sheep farms the lowest (Figure 3). There is a marginal difference between LFA and arable farms, with arable farms having slightly higher footprints but this difference is almost negligible. However, all the farm types in Scotland, with the exception of Dairy, are seen to have footprints which are smaller than their overall biocapacity. Considering that the overall EF estimates for farming in Scotland are relatively low, though the Dairy sector has a significantly higher impact than the rest of the farm types, this effect is not enough to make a difference to the overall results for Scottish agriculture.

Table 6. Ecological Footprints of Different Farm Types 2005-06

	LFA Specialist Sheep	LFA Specialist Beef	LFA Cattle and Sheep	Dairy	Cereals	General Cropping	Mixed
Average size of farm (hectares)	525	137	350	126	153	176	303
Biocapacity (gha)	428	122	372	130	598	622	509
Ecological Footprint (gha)	226	81	204	98	343	392	328
Footprint with CH ₄ (gha)	244	118	238	165	347	402	364
EF/Biocapacity	0.53	0.66	0.55	0.75	0.57	0.63	0.64
EF (CH ₄)/Biocapacity	0.57	0.96	0.64	1.27	0.58	0.65	0.71

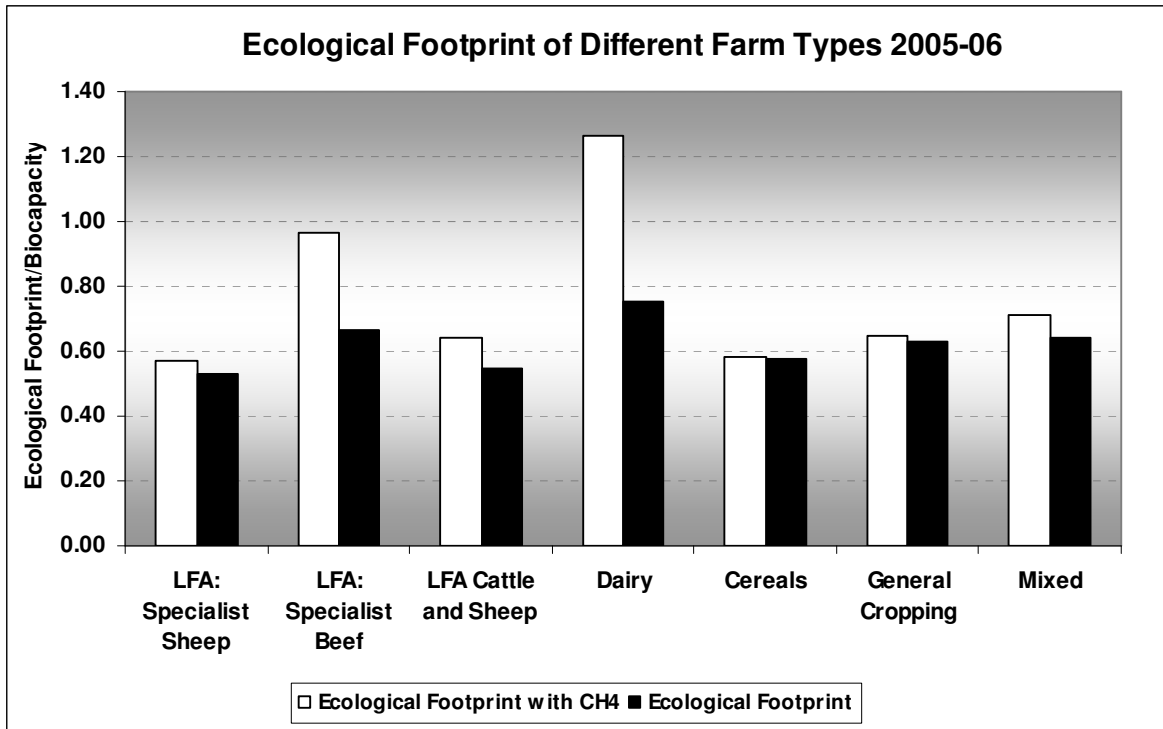


Figure 3. Cross Sector analysis of Farm Types in Scotland

4.3 Ecological Footprints and Farm Performance

In order to study the link, if any, between farm performance and EF, top and bottom performers ranked according to NFI were assessed using the EF. Overall no conclusive trends were identified though, for all farm types except Dairy farms lower performing farms recorded

slightly higher EF estimates. Both lower and higher performing farms of all types except Dairy recorded EF estimates within the threshold limit of 1, and both higher and lower performing Dairy farms are seen to have values of EF higher than 1. This reinforces the conclusion in Section 4.2 that all farm types in Scotland have smaller environmental impacts as defined by the EF, with the exception of dairy farms.

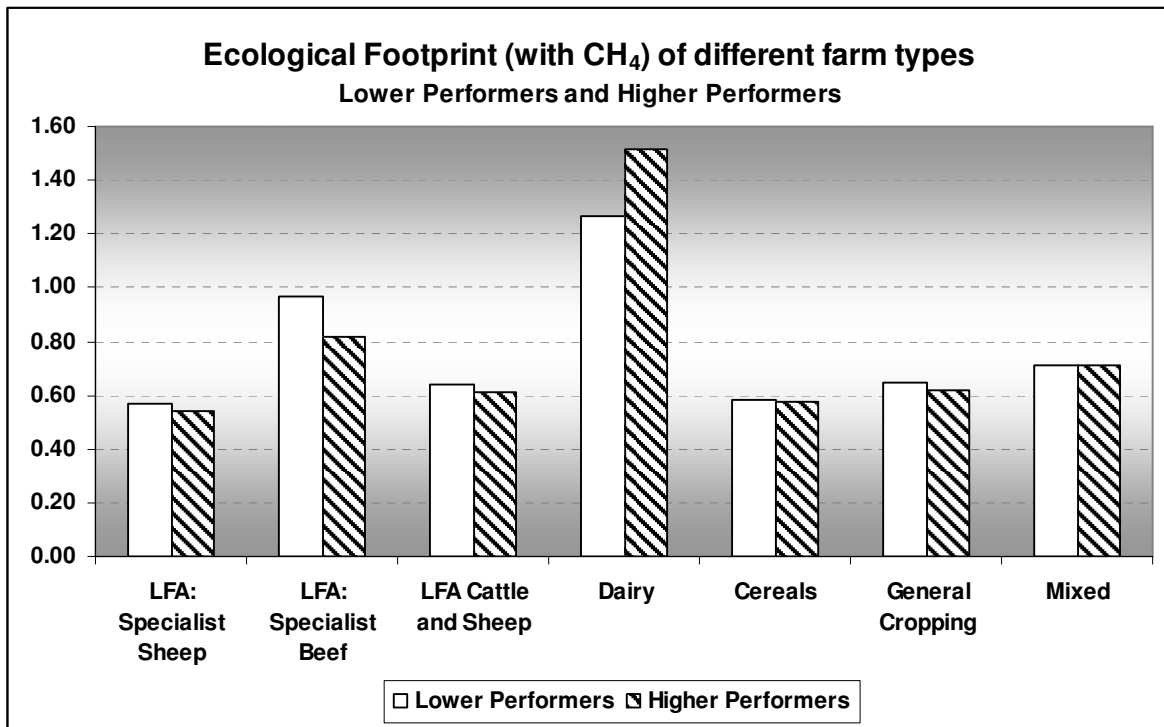


Figure 4. Cross Sector analysis of High and Low Performing farm types

4.4 Modes of Expression

Van der Werf (2007) compared different environmental assessment methods for farms per unit area and per unit product with varying results, and suggests the need to consider both. This study expresses the EF per unit area and per unit output, with the results of both differing from each other. An analysis of this variance confirms Van der Werf (2007) and takes this a step further to suggest that expressing the EF per unit area can be used as a measure of

intensification or extensification of a farm, and that expressing the EF unit output can give an idea of the efficiency of resource use of a farming system.

Halberg *et al.*, (2005) identify that using area based results has the potential of being able to identify whether a farm system is extensive or intensive compared to another. When comparing stocking densities of livestock farms in Scotland it is conclusive that dairy farming is the most intensive type as demonstrated by a stocking density of 2.11 livestock units supported on a hectare of land, and sheep farms the least intensive type as demonstrated by a stocking density of 0.08 livestock units per hectare (Figure 5). EF estimates expressed per unit area show a corresponding trend with dairy farms having the largest footprint, followed by Specialist Beef farms, Cattle and Sheep farms and finally Specialist Sheep farms. As presented in Section 1.4, sheep farms can also be identified as the most extensive farm type in Scotland. Hence using the EF per unit area can measure the extent to which a farm system is extensive or intensive compared to another.

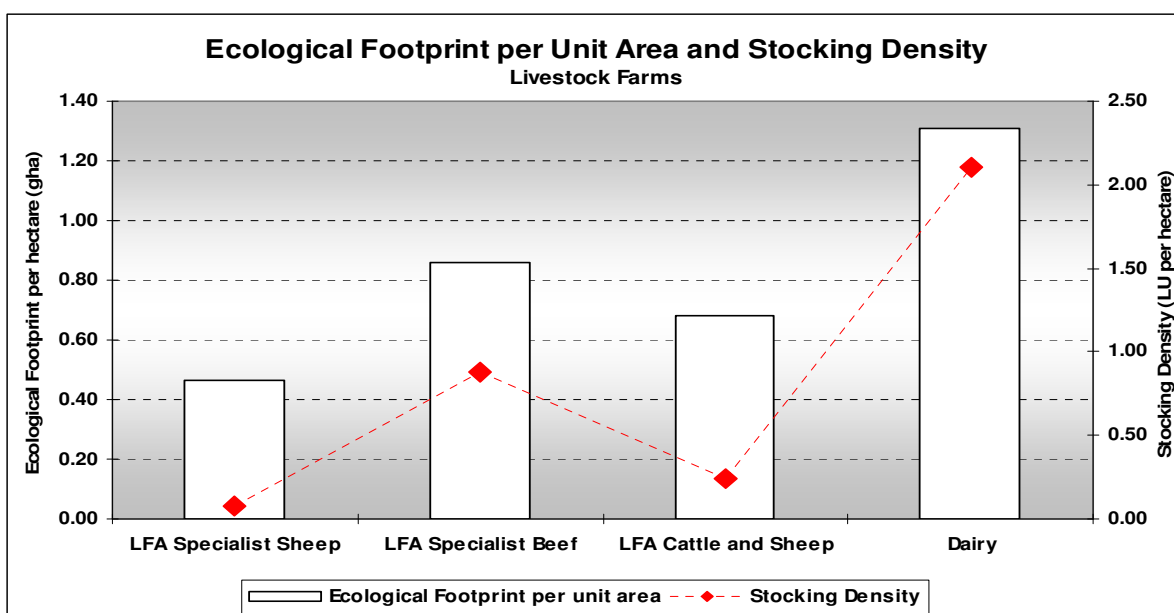


Figure 5. Livestock farms ranked by EF expressed per unit area

Measuring the intensiveness or extensiveness in a farming system does to an extent indicate the impact of the farm on the environment; however it does not necessarily indicate sustainability of a farming system. A farm which becomes more extensive will have a lower

degree of environmental impact, but in order for the lowering of impact to be maintained this extensification should ideally be the result of an informed choice or deliberate change in management strategy. Sheep farms in Scotland have always been extensive and had a lower environmental impact due to natural constraints (WWF, 2004), not a deliberate choice of maintaining land in a more environmentally friendly way. Further, in light of the recent CAP reforms, if this extensification in farming in Scotland is the result of a farm being able to survive on a government payment instead of livestock or crops maintained intensively, it only means that globally the environmental impact has been exported to another region of the world.

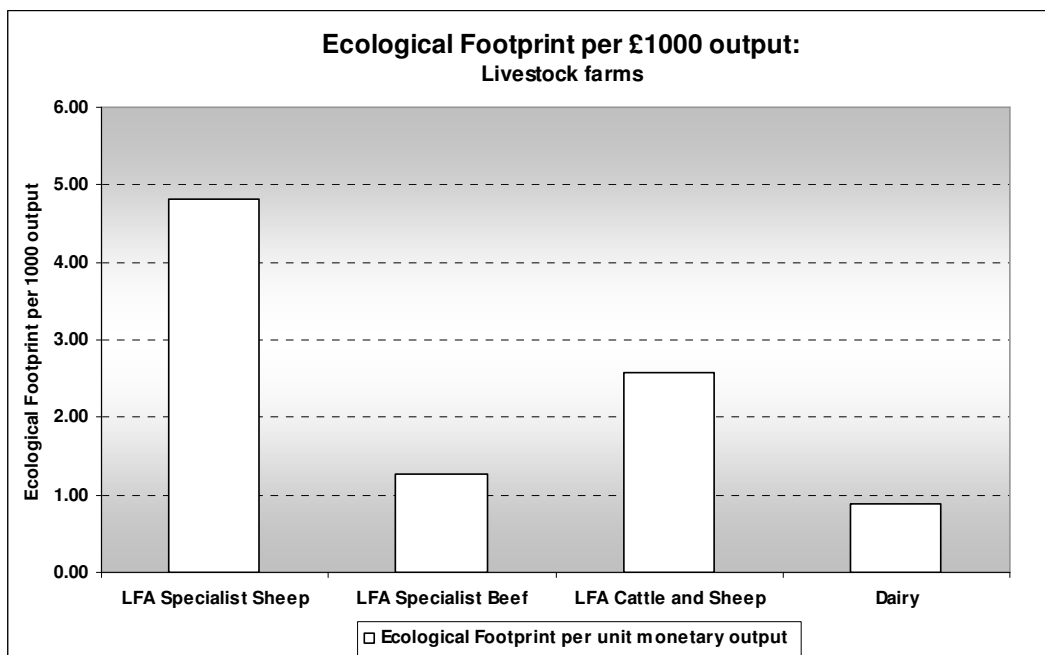


Figure 6. Livestock farms ranked by EF expressed per unit monetary output

When EF results are expressed per unit monetary output, however, a reverse trend is observed (Figure 6). Dairy farms ranked the lowest (0.71 – 0.88gha), and sheep farms the highest (4.81gha). Taking the Ecological Footprint as a measure of ecological resource use these results imply that dairy farms in Scotland use fewer resources to produce a unit of monetary output, and sheep farms use more resources and produce more emissions to produce the same unit of monetary output. It is generally acknowledged that dairy farmers in the UK are the most efficient in terms of maximizing output from inputs in Europe (MDC, 2006), while sheep

farmers in Scotland use a lot more resources to maintain the larger areas of land they occupy and in turn produce a relatively lower amount of output (LGP, 2006). Hence, using the EF per unit monetary output it is possible to measure the efficiency of ecological resource use in a farming system. However it is important to note, that efficiency of ecological resource use demonstrated here is different from the concept of ‘eco-efficiency⁷’, and measures only how efficient a farm system is in using its resource to produce economic output.

5. Conclusion

It has been seen that overall Scottish agriculture has an ecological impact that can be sustained on agricultural land in Scotland, and that the only type of farming, of seven types, that is progressing unsustainably is Dairy farming. It is further observed that though Dairy farms are the most intensive type in Scotland, they are also the most efficient in producing monetary output from the resources they have used. These conclusions have important implications for Scotland, as little work so far categorizes ecological impact by farm category anywhere in the UK. The result that overall Scottish agriculture has a low ecological impact is also important for European agriculture as till date it has been a widely acknowledged fact that agricultural systems in Europe have wrecked havoc on the environment for decades by intensifying livestock production and increasing fertilizer and pesticide inputs into the land.

There is a wide range that exists between an indicator that barely measures the environmental impact of a farm and an indicator that satisfactorily measures sustainable agriculture. Satisfactory indicators of environmental performance that truly capture the essence of sustainable development have not been designed in almost any section of the economy, and most indicators of environmental performance fall short in some respect or the other when measuring sustainability comes into the question. A relevant indicator for farming needs to provide accurate information about ecological impacts of farming and produce results in a

⁷Eco-efficiency aims to reduce material and energy intensity, reduce toxic dispersion, enhance material recyclability, maximize the sustainable use of renewable resources, extend product durability and increase service intensity. (McGregor *et al.*, 2004).

form that is easily communicable to a wider audience. Though the EF methodology has caveats, using this indicator for the assessment in this study has produced results in a single comparable unit which can be further expressed per unit area or per monetary output depending on the direction of the assessment. Further, using the EF has demonstrated the relative impacts of different farm types and provided an overall integrated assessment of farm systems in Scotland.

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Discussion

An analysis of the results presented has been outlined in Section 4 of Paper 2. However, in order to present research findings that are unbiased and can be used for further work, it is important to critically assess the methodology used. This paper discusses the main assumptions and limitations of the study, and identifies areas which could be modified in future work.

1. Assumptions and Uncertainties

The main assumptions underlying the methodology and the uncertainties associated with them are as follows:

1. Using the National Footprint Accounts as a first step assumes that the National Footprint Account estimate of the EF of the UK is an accurate figure which tracks the major consumption of the population and converts it accurately into land areas.

The National Footprint Accounts (NFA) maintains a comprehensive database on Ecological Footprint (EF) estimates for countries around the world, and updates these annually. However, of all the EF methodologies presented in the literature, the NFA methodology is the most vulnerable to criticism. The only waste assimilation this method includes is CO₂ emissions from fossil fuels. Other forms of waste and pollution, other greenhouse gas emissions and emissions from sources other than the burning of fossil fuels are not considered. Further the equivalence and yield factors have also been widely criticized (Van den Bergh and Verbruggen, 1999; Wiedmann and Lenzen, 2006) as the former are based on the potential productivity of an area and does not reflect land use practices at all, and the latter are calculated on a yearly average by national organizations and are seen to fluctuate, influencing the EF results.

2. Biocapacity of different farm types has been calculated using the NFA equivalence and yield factors.

The biocapacity of each of the farm types have been calculated using the NFA equivalence and yield factors which represent ‘global potential productivity’ (Wackernagel *et al.*, 2005). As Wiedmann and Lenzen (2006) point out, using global averages to convert local hectares into the global hectare numeraire brings about inconsistencies in the results as all primary production categories are treated equally irrespective of their origin. For example, a 250 hectare Specialist Sheep farm in Scotland with 200 hectares of pastureland and 50 hectares of cropland will have the same biocapacity as any farm across the world with the same division of crop and pasture land. In reality, however, the biocapacity of a farm in Scotland may be completely different from one in, say, New Zealand. Hence the EF estimates calculated are sustainable with respect to world average biocapacity, but may or may not be if conversion factors used reflected local yields.

3. The results presented are based on the assumption that the dataset used represents an overall picture of Scottish Farming

The Farm Accounts Survey is carried out in a representative sample of 500 Scottish Farms. The sample represents farms of the different categories of classification over a certain size. There is a minimum threshold, smaller than which farms are not represented in the Survey. Defra estimates that the farms that fall below the threshold cover approximately 10% of agricultural land in the UK. This means that the dataset used in this paper is representative only of larger farms that fall into a higher performance category. It is probable, however, that smaller farms with less efficient practice could have a high cumulative impact on the environment, and this is not captured in the results. Further, data for the Lowland Cattle and Sheep category was not available for assessment, and this affects the results of the comparison of farm types. Lowland cattle farming is a minority in Scotland, but is associated with a much more intensive method of farming than farms in the LFA areas (WWF, 2004).

4. In using BL³ it is assumed that expenditure is an accurate measure of consumption, and that environmental impacts associated with physical commodities are reflected by their prices.

In most cases this assumption is held to be true. Prices of different commodities in one year allow a comparison of the impacts of commodities, and in the trend analysis the prices for different commodities have been corrected to better reflect physical quantities. However, in extreme cases prices may not completely capture the magnitude of consumption. For example, a farm may use the same amount of a commodity over two years, but due to special circumstances may pay much less for this commodity in one of the years. In this case the software would allocate resources used to create the commodity as less in the year it was paid less for, unless these prices were corrected before inputting into the software. This is not common occurrence, however, and in this study prices are aggregated and hence extremely low or high prices paid for commodities are avoided.

5. In disaggregating the dataset, it was assumed that the break down of certain categories were proportionate to a complementary dataset in England.

In disaggregating the 'Other Livestock Expenses' and 'Other Crop Expenses' categories, the percentages used to break down the aggregate figures into expenditure items like veterinary and medical costs, fungicides and pesticides, sundry crop expenses and haulage, were obtained from the Farm Business Survey in England data. It was necessary to use this method as, the actual disaggregated data was not available in the time it was required, and the Farm Business Survey in England uses the same method to collect, group and present the data as the Farm Accounts Survey in Scotland. The uncertainty associated with this method of disaggregation is immense due to the variation in climate, topography and soils in Scotland and England and the fact that prices of different agricultural commodities and services vary within a geographical area. For example, in calculating the standard gross margins of different enterprises, LGP (2005; 2006) note that costs of veterinary and medicine and haulage vary widely in Scotland, with farms in the Western Isles paying a much higher price for these than those in lowland East Scotland. However, it has been observed when computing the results of the analysis, that the bulk of the EF estimate for a farm is attributed to the direct impacts of the farm, and only a

small proportion is dependant on the indirect impacts (Table 1). This can be explained by the fact that expenditure amounts for Scottish farms in general are quite low, varying between £80,000 and £100,000 a year. Hence any distortion in the data that may have arisen through the disaggregation process should not have a significant effect on the EF estimates presented.

Table 1. Commodity breakdown of the Lower Performing Mixed Farm category

Rank	Commodity	Impact
1	Direct Impacts of Mixed Farm category	321 gha
2	Agriculture	35.3 gha
3	Food and drink	2.23 gha
4	Electricity production and distribution	2.17 gha
5	Mechanical machinery and equipment	2.01 gha
6	Fertilisers	0.45 gha
7	Road transport	0.18 gha
8	Wholesale distribution	0.08 gha
9	Coke ovens, refined petroleum & nuclear fuel	0.06 gha
10	Real estate activities	0.05 gha
11	Construction	0.021 gha
12	Insurance and pension funds	0.020 gha
13	Motor vehicle distribution and repair, automotive fuel retail	0.017 gha
14	Health and social work	0.015 gha
15	Legal, consultancy and other business services	0.010 gha

6. In disaggregating land areas on a farm, rough grazing land is assumed to be the same as pasture land as defined by the NFA.

Grassland in Scotland varies by geographical area. Rough grazing land is associated with very low intensity farming and semi natural vegetation, and accounts for over 50% of all agricultural land in Scotland (SNH, 1999; RERAD, 2007). Smooth grazing land or permanent pasture is land that requires constant inputs in terms of fertilizer, water and maintenance. The NFA methodology does not differentiate between pasture types, and hence all rough grazing land associated with LFA farms was assumed to be equivalent to permanent pasture land and have been allocated to this component of the EF estimates. This has impacted the results of the analysis, as LFA farms which represent very low intensity farming might have been estimated to have a larger footprint than if the rough grazing land was separately accounted for.

2. Future Areas of Research

Most research into farming indicators for environmental performance presents the indicator or its evaluation in published literature, from experimental data tested in a sample farm or set of sample farms. There is little work published on the actual implementation of these indicators at farm level and few studies have looked at farmers views on different indicators. Halberg *et al.* (2005) evaluated the views of farmers with respect to environmental indicators in different parts of Europe and demonstrated that farmers are interested in including environmental aspects into their management strategies, especially if they understand the issues and can better their performance without much extra cost. The EF has been seen to have its advantages and limitations, and though the applications paper concludes that farming in Scotland has a small ecological impact, these conclusions would be better proved if field tested among those who will actually use farming indicators; i.e. farmers and agro-economists. It is recommended that further research into farming indicators include more interaction with farmers and agro-economists as these are the stakeholders who will have the most pragmatic viewpoint when assessing an indicator of environmental performance at farm level.

Further, for an indicator to result in improved environmental performance farmers need to be aware of the implications of indicator results, and how to implement changes in management strategy related to these results. Halberg *et al.* (2005) demonstrates that the most successful environmental indicator systems on farms were those linked with advisory services for farm management. The EF has already been made easily available for use and analysis through the REAP tool for local authorities (SEI-Y, 2004) and through BL³ for organizations. If modified in a way that is easily implemented by farmers it could be useful for indicating the environmental impacts of resource use on farms and farm efficiency.

As has been mentioned over and over again in both the papers, the main limitation of the EF is that methodologies tend to leave out some components of ecological demand on nature. On a national scale some of these components may not make a significant difference to the results of the analysis, however at a sub national scale these may completely turn around the results

of the study. This has been demonstrated in the applications paper, where including methane emissions increased the status of dairy farming from below threshold to above threshold. Further areas of work on the EF should aim to iron out some of these creases so that the EF is better suited to different sub national level assessments. For agriculture, non greenhouse gas emissions are an essential factor which must be included in assessments of agriculture. This paper includes methane emissions from enteric fermentation and manure management, but others like nitrous oxide emissions from the use of fertilizers and pesticides, nitrous oxide emissions from manure storage and emissions from agricultural soils all contribute significantly to agricultural emissions in the UK (Baggott *et al.*, 2007) and should be part of any agricultural assessment.

1857 words

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APPENDIX 1: ECOLOGICAL FOOTPRINT RESULTS (DETAILED BREAKDOWN)

Table 1. Income Results – Ecological Footprint

	LFA: Specialist Sheep		LFA: Specialist Beef		LFA Cattle and Sheep		Dairy		Cereals		General Cropping		Mixed	
	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%
Farm Characteristics														
Average size of farm (hectares)	525	686	137	258	350	620	126	161	153	183	176	182	303	209
Average Cropland	0	0	6	11	7	10	10	6	98	96	103	108	73	58
Average Pasture	594	705	123	221	462	732	103	129	66	51	60	67	138	101
Biocapacity (gha)	428	508	122	221	372	583	130	127	598	576	622	655	509	399
Output	50735	57128	93517	130228	92034	136111	184916	210285	186542	270072	134166	128153	168903	156261
Ecological Footprint	226	260	81	134	204	316	98	114	343	323	392	398	328	247
Fossil fuel energy Footprint	10.7	6.11	17.5	17.8	15.6	17.3	30.4	28.1	28.4	19.6	38.9	30.2	30	18.8
Nuclear energy Footprint	0.54	0.35	0.8	0.77	0.73	0.88	2.84	2.61	1.23	0.77	1.62	1.35	1.14	0.82
Crop land Footprint	0.7	0.11	17.9	34.9	20.8	32.5	22.1	31.2	288	282.8	322	335	238	185
Pasture Footprint	214	254	44.4	80.5	166	265	41.6	51	24.7	19.5	29	31	58.2	41.8
Built land Footprint	0.06	0.032	0.12	0.13	0.1	0.12	0.13	0.13	0.2	0.14	0.3	0.17	0.15	0.1
Sea Footprint	0.14	0.06	0.23	0.18	0.23	0.19	0.77	0.82	0.04	0.04	0.12	0.13	0.49	0.39
Forest Footprint	0.024	0.012	0.04	0.04	0.04	0.04	0.13	0.13	0.06	0.04	0.09	0.07	0.11	0.07
EF/Biocapacity	0.53	0.51	0.66	0.61	0.55	0.54	0.75	0.90	0.57	0.56	0.63	0.61	0.64	0.62
EF per Unit Area	0.43	0.38	0.59	0.52	0.58	0.51	0.78	0.71	2.24	1.77	2.23	2.19	1.08	1.18
EF per £1000 Output	4.45	4.55	0.87	1.03	2.22	2.32	0.53	0.54	1.84	1.20	2.92	3.11	1.94	1.58

Table 2. Income Results – Ecological Footprint (with methane emissions)

	LFA: Specialist Sheep		LFA: Specialist Beef		LFA Cattle and Sheep		Dairy		Cereals		General Cropping		Mixed	
	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%	Lower 25%	Upper 25%
Farm Characteristics														
Average size of farm (hectares)	525	686	137	258	350	620	126	161	153	183	176	182	303	209
Average Cropland	0	0	6	11	7	10	10	6	98	96	103	108	73	58
Average Pasture	594	705	123	221	462	732	103	129	66	51	60	67	138	101
Biocapacity (gha)	428	508	122	221	372	583	130	127	598	576	622	655	509	399
Output	50735	57128	93517	130228	92034	136111	184916	210285	186542	270072	134166	128153	168903	156261
Footprint with CH4	244	276	118	180	238	358	165	192	347	331	402	407	364	282
Fossil fuel energy Footprint	28.7	21.7	55	63.5	49.4	60	97.2	106	32.7	27.6	48.8	39.7	65.6	54.1
Nuclear energy Footprint	0.54	0.35	0.8	0.77	0.73	0.88	2.84	2.61	1.23	0.77	1.62	1.35	1.14	0.82
Crop land Footprint	0.7	0.11	17.9	34.9	20.8	32.5	22.1	31.2	288	282.8	322	335	238	185
Pasture Footprint	214	254	44.4	80.5	166	265	41.6	51	24.7	19.5	29	31	58.2	41.8
Built land Footprint	0.06	0.032	0.12	0.13	0.1	0.12	0.13	0.13	0.2	0.14	0.3	0.17	0.15	0.1
Sea Footprint	0.14	0.06	0.23	0.18	0.23	0.19	0.77	0.82	0.04	0.04	0.12	0.13	0.49	0.39
Forest Footprint	0.024	0.012	0.04	0.04	0.04	0.04	0.13	0.13	0.06	0.04	0.09	0.07	0.11	0.07
EF/Biocapacity	0.57	0.54	0.96	0.81	0.64	0.61	1.27	1.52	0.58	0.57	0.65	0.62	0.71	0.71
EF per Unit Area	0.46	0.40	0.86	0.70	0.68	0.58	1.31	1.19	2.27	1.81	2.28	2.24	1.20	1.35
EF per £1000 Output	4.81	4.83	1.26	1.38	2.59	2.63	0.89	0.91	1.86	1.23	3.00	3.18	2.16	1.80

APPENDIX 2: DATA SOURCES AND DISAGGREGATION

This appendix gives details of the data sources used in the assessment of Scottish agriculture and the reasons behind the choice of these. It also outlines the disaggregation procedure that was followed to manipulate the data in order to use it in the BL³ tool.

Farm Incomes in Scotland Dataset

National level data was chosen for this study as it allows the results of this study to be compared with others in the future. Another reason for using nationally collected data for Scotland, instead of data for a particular farm, is that the calculations aimed to provide an accurate macro-level picture of Scottish Agriculture and overall conclusions about farming systems in Scotland could be drawn from an analysis using this data.

The Farm Incomes in Scotland reports are based on the Farm Accounts Survey, which is an annual survey carried out the Scottish Agricultural College. It covers a representative sample of farms in Scotland (500 farms) and presents statistical results on the incomes and expenditure of different farm types. The complementary survey to this in England is called the Farm Business Survey and presents complementary results for England and Wales.

The assessment of Scottish Agriculture over time was based on the annual monetary inputs and outputs figures presented for the 'All Types' category in the dataset. This category presents the average figures of all the farm types in the representative sample of farms surveyed. The data for the higher and lower performing farms was taken from the revenue and expenditure information of the farms in the upper and lower quartiles when ranked by Net Farm Income (NFI)¹. Though there is considerable debate on how accurate NFI is in reflecting

¹ Net Farm Income (NFI) is calculated by subtracting all inputs to a farm (i.e. labour, feed, machinery) from outputs (i.e. crops, cattle output, grants and subsidies).

actual farm performance, it is the most widely used measure in the UK for trend analysis in agriculture (SEERAD, 2007).

Disaggregation of Expenditure Categories

These datasets are used to analyze different trends in agriculture and hence present data in aggregated categories. In order to use these for EF calculation, however, it was necessary to obtain prices for individual items of expenditure. Disaggregating the data was done using a variety of different sources as explained below. The aggregated categories in the dataset are presented in Table 1.

Table 1. Data categories and the sources used to disaggregate each

Category	Description	Source for Disaggregation
Miscellaneous	Electricity, vehicle tax, insurance, secretarial costs	Farm Business Benchmarking data
Other Crop Expenses	Crop sprays, sundry crop expenses including items like net wrap for bales of straw etc.	Farm Business Survey Results
Other Livestock Expenses	Veterinary and medical costs, haulage costs (transport), costs of bedding material	Farm Business Survey Results
Land and Building Costs	Rent paid by tenants and rental value of owner-occupied farms, Repairs by occupiers.	Farm Business Survey Results
Machinery Costs	Expenditure on machinery repairs, small tools, contract work and fuel and oil	Farm Business Benchmarking data

In order to allocate these correctly in BL³ it was necessary to disaggregate these items. As the original data could not be obtained due to time constraints, this data was disaggregated using other sources of information. The Farm Accounts Survey data is used in the construction of the Defra Farm Business Benchmarking website, and this site presents the data in a disaggregated form. However, this source could only be used for two categories as the details provided include only Fixed Costs. The other source that was consulted was the Farm

Business Survey results, as these are available in spreadsheets and present a detailed break down of each category of expenditure.

After expenditure information was obtained through disaggregation, it was necessary to obtain details of the direct impacts, i.e. electricity and fuel use on the farm, emissions from farm activity etc. The Farm Incomes dataset only provides details of expenditure and revenue, and there is no source that provides these details in terms of kwh of electricity and litres of diesel consumed. Hence it was necessary to use the disaggregated data for electricity and fuel in order to obtain this information. The prices for each of these commodities were obtained from the Farm Management Handbook series (SAC, 2006) which provides details of costs and gross margins for farmers across Scotland.

Calculating and allocating Methane Emissions

In order to calculate methane emissions, UK emission factors were used wherever they were available, and for other livestock, IPCC emission factors were used. A summary of these is presented in Table 3. As the EF has no component for greenhouse gas emissions other than carbon dioxide, the methane emissions accounted for were converted into CO₂ equivalents using the standard IPCC factors (Global Warming Potential of Methane is 21) and then added to the footprint calculations. Hence in the results of this paper, these emissions appear as part of the fossil fuel footprint component of the EF.

Table 4. Emission Factors for Methane

Livestock	Emission Factor Used (kg CH ₄ /head/year)		Source
	Enteric Fermentation	Manure Management	
Dairy Cattle	100	14	NAEI, 2007
Sheep	8	0.19	IPCC factors from EEA (2006)
Other Cattle	48	6	IPCC factors from EEA (2006)

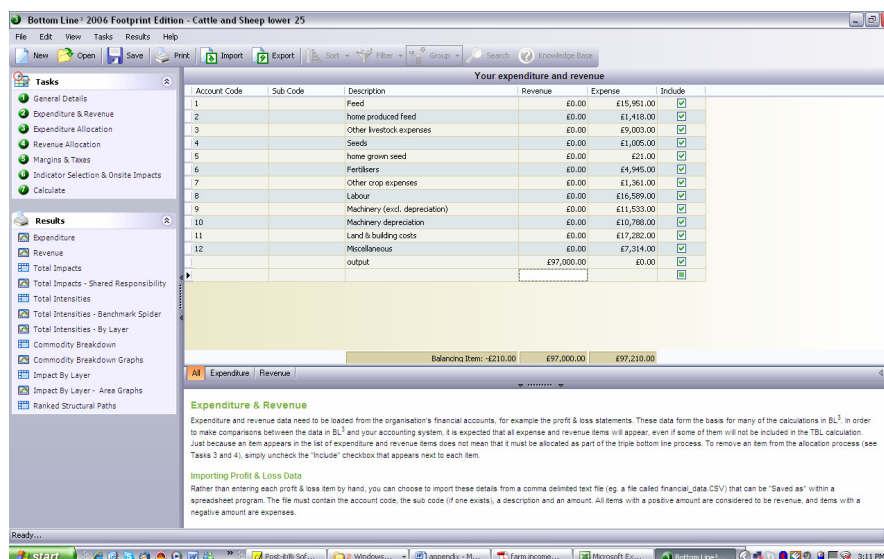
APPENDIX 3: STEPWISE PROCEDURE FOR USING BOTTOMLINE³

This appendix includes a detailed description of how the Ecological Footprint calculations were carried out and the different stages of inputting and allocating data in the BL³ tool.

In order to calculate the Ecological Footprints of agriculture in Scotland, five footprint projects were used to calculate the 'Average Farm' footprint across five years. For the incomes analysis, upper and lower performing farms of seven farm types were analyzed against the average type producing twenty one footprints. Each of these were converted into global hectare units in order to analyze the results as a whole. The procedure for using the BL³ model is as follows.

The basic steps involved in using BL³ are inputting the data, allocating the revenue and expenditure categories with the concordance table to the UK Standard Industrial Classification categories and allocating the on-site or direct impacts of the farm.

Step 1: Inputting data



The data used for Scottish agriculture were stored on comma delimited (.csv) files as these can be directly imported into BL³ as shown below. As revenue data was not necessary for footprint calculations these were omitted from the assessment. The tool recognizes negative expenditure amounts as revenue so it is necessary to make the changes to the data once it is entered into the tool.

Step 2: Allocation of expenditure items

This step allocates the expenditure items of the farms according to the national economic categories. For each item it is necessary to allocate how much of that item comes from which economic sector.

Concordance with ABS National Accounts				Expenditure Allocation							
ABS Sector	Scaled Benchmark	Total	Method	1	2	3	4	5	6	7	8
				Feed	home produced	Other livestock	Seeds	home grown seed	Fertilisers	Other crop expenses	Labour
				£15,951	£1,418	£9,003	£1,005	£21	£4,945	£1,361	£16,585
Level: Other											
Category: Other											
Taxes less subsidies o...	-£714	£7,491	Allocated		100%	26%	100%	100%			
Compensation of empl...	£12,116	£19,703	Allocated								100%
Gross operating surplus	£22,796	£0	Estimate								
Inputs from stocks	£352	£0	Estimate								
Imports	£20,322	£0	Estimate								
Level: Primary Industry											
Category: Agriculture											
Agriculture	£7,662	£0	Estimate								
Category: Fishing											
Fishing	£0	£0	Estimate								
Category: Forestry											
Forestry	£9	£0	Estimate								
Category: Mining											
Coal extraction	£0	£0	Estimate								
Oil and gas extraction	£4	£0	Estimate								
0 % Estimated	£97,210	£97,210		100%	100%	100%	100%	100%	100%	100%	100%

Expenditure Allocation

In order to calculate the TBL impacts of a supply chain, BL³ uses accurate national sectoral impact data together with an organisation's expenditure data. Task 3 - expenditure allocation - is required because organisations have their own way of classifying, or describing, financial account items. Like an organisation, the National Accounts from the UK Office for National Statistics (ONS) have their way of classifying what we call goods and services, and what the ONS refers to as products. Because this software links all kinds of organisations to the National Accounts, the issue is to translate your account into the "language" of the National Accounts. You can do this using a conversion table (also called a Concordance Table). The conversion table is like a map that converts your organisation's classification system into that of the National Accounts. This map contains each one of your expenditure items, and re-classifies it into one or more product groups from the National Accounts.

How do the National Accounts classify products?

The classifications used in this software package are the product groups from the National Accounts published regularly by the Office for National Statistics (ONS). Random examples for ONS product groups are:

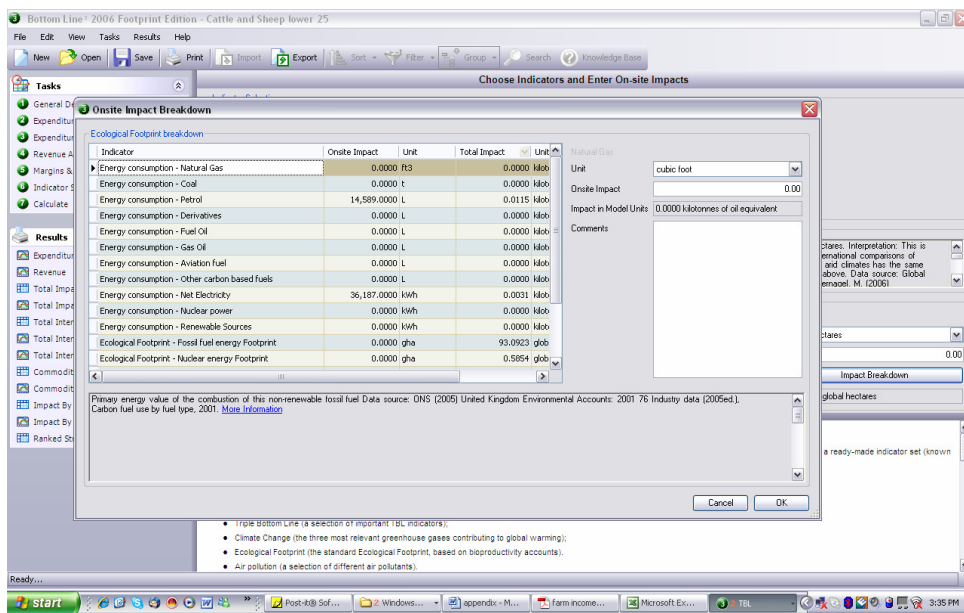
- Fish
- Meat, etc.

For example, in the above picture 26% of Other Livestock expense is allocated to the agricultural sector, as 26% of this category is spent on bedding materials which are primary agricultural products. The tool is built in with the National Footprint Account total EF estimate for the UK. This total is disaggregated using the national input-output tables, and when items of expenditure are allocated to the UK national classification they are

automatically allocated an EF estimate. All these estimates are aggregated together to quantify the impacts from the supply chain.

Step 3: Allocation of direct impacts

Direct impacts are allocated in the next step and are input directly in terms of liters of fuel or kwh of electricity. This step is flexible in that different items of direct impacts can be entered in a variety of units. This data is then automatically converted into CO₂ emissions and is added onto the fossil fuel footprint.



In this step land use is also allocated in terms of pasture and cropland of farms. The data from this step makes up the primary EF estimate and is responsible for the majority of the EF of Scottish farms. This is because farms in Scotland occupy a wide area, but they use only a limited range of materials and hence the supply chain impacts are much less than the primary impact.

APPENDIX 4: ECOLOGICAL ECONOMICS - GUIDANCE FOR AUTHORS

Ecological Economics is the trans-disciplinary journal of the International Society for Ecological Economics.

Manuscript Guidelines

1. Manuscripts are to be written in English. Authors whose native language is not English are advised to seek the help of an English-speaking colleague, if possible, before submitting their manuscripts.
2. Manuscripts should fall into one of five categories: News and Views, Commentary, Surveys, Methodological and Ideological Options or Analysis.
3. News and Views are intended to be topical and timely short pieces reviewed by the editor and/or one outside reviewer at the editor's discretion. These may include editorials, letters to the editor, news items, and policy discussions. Letters to the Editor should not contain references to personalities, but rather focus on ideas. Maximum 1500 words (600 words for letters).

Commentaries are essays discussing critical issues. They are reviewed by three outside reviewers with the criteria weighted toward quality of the exposition and importance of the issue. 4000 words or 12 double-spaced pages. Surveys examine and review important general subject areas. They are reviewed by three outside reviewers with the criteria weighted toward importance of the subject and clarity of exposition. 8000 words or 25 double-spaced pages.

Manuscripts devoted to Methodological and Ideological Options develop new methodologies or investigate the implications of various ideological assumptions. They are reviewed by three outside reviewers with criteria weighted toward originality and potential usefulness of the methodology or ideological option. These should not exceed 8000 words or 25 double-spaced pages. Research articles devoted to analysis of important questions in the field are reviewed by three outside reviewers with the criteria weighted toward originality, quality, accuracy of the analysis, and importance of the question. Maximum 8000 words or 25 double-spaced pages. Reviews of recent books in the field are reviewed by one outside reviewer with criteria weighted toward clarity and accuracy of the review and importance of the book to the field. The maximum length for book reviews is 1200 words or 4 double-spaced pages. Letters to the Editor should be less than 2 pages of 600 words.

4. Manuscripts, book reviews and letters to the Editor should be typewritten, typed on one side of the paper (if possible with numbered lines), with wide margins and double spacing throughout. The same applies for abstracts, footnotes and references. Every page of the manuscript, including the title page, references and tables, should be

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Abstract

Key words (four to six)

Introduction

Material studied, area descriptions, methods, techniques

Results

Discussion

Conclusion

Acknowledgments

References

Tables

Figure captions

6. In typing the manuscript, titles and subtitles should not run within the text. They should be typed on a separate line, without indentation. Use lower-case letter type.

7. SI units should be used.
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8. Any explanation essential to the understanding of the table should be given as a footnote at the bottom of the table.

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2. In the text refer to the author's name (without initial) and year of publication, followed, if necessary, by a short reference to appropriate pages. Examples: "Since Peterson

(1989) has shown that...". "This is in agreement with results obtained later (Kramer, 1992, pp. 12-16)".

3. If reference is made in the text to a publication written by more than two authors, the name of the first author should be used followed by "et al." This indication, however, should never be used in the list of references. In this list, names of first author and co-authors should be mentioned.
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Ayres, R.U., 1993. Cowboys, cornucopians and long-run sustainability. *Ecol. Econ.*, 8:189-207.

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Reiche, E.-W., 1993. Modelling water and nitrogen dynamics on catchment scale. In: B. Breckling and F. Muller (Editors), *State-of-the-Art in Ecological Modelling*. *Ecol. Model.*, 75/76; 371-384.

For books

Ahmad, Y., El Serafy, S. and Lutz, E. (Editors), 1989. *Environmental Accounting for Sustainable Development*. The World Bank, Washington, DC, 100 pp.

For multi-author books

Daly, H.E., 1991. Ecological economics and sustainable development. In: C. Rossi and E. Tiezzi (Editors), *Ecological Physical Chemistry*. Elsevier, Amsterdam, pp. 185-201.

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APPENDIX 5: AGRICULTURE, ECOSYSTEMS AND ENVIRONMENT - GUIDANCE FOR AUTHORS

Guide for Authors

Agriculture, Ecosystems & Environment deals with the interface between agriculture and the environment. Preference is given to papers that develop and apply interdisciplinarity, bridge scientific disciplines, integrate scientific analyses derived from different perspectives of agroecosystem sustainability, and are put in as wide an international or comparative context as possible. It is addressed to scientists in agriculture, food production, agroforestry, ecology, environment, earth and resource management, and administrators and policy-makers in these fields.

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- Results
- Discussion
- Conclusion
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Rice, K., 1992. Theory and conceptual issues. In: Gall, G.A.E., Staton, M. (Eds.), *Integrating Conversation Biology and Agricultural Production.* *Agric. Ecosyst. Environ.* 42, 9-26.
 - c. *For books*
Gaugh, Jr., H.G., 1992. *Statistical Analysis of Regional Yield Trials.* Elsevier, Amsterdam.
 - d. *For multi-author books*
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