A Novel Technique for Identifying Environmental Outcomes from Agricultural Practices

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Abstract

There are a wide range of techniques that can be used for evaluating environmental impacts of agriculture, but they have not previously been used to identify the contribution individual farming activities make toward environmental outcomes or for prioritising activities to ensure maximum benefits. This paper reports a novel technique for identifying how different activities influence environmental outcomes. The methodology is based upon traditional EIA techniques. Knowledge is collated from documented evidence and structured within a database such that the causal processes by which different activities influence outcomes can be identified. Cause and effect chains are created and each link is weighted according to the strength of the relationship between the two components. The entire cause-effect chain assumes the weighting of the weakest link. This is used to identify the strengths and weakness of individual practices or groups of activities. This paper explains the process using examples from agricultural production and policy in the UK and Europe for illustration.

Keywords

Environmental Impact Assessment; Weak-link Approach; Cause-effect chains; Agriculture

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Introduction

Sustainable development (Defra, 2005) is key concept that has emerged in society over the past half-century. Increasing global populations and decreasing natural resources have lead to concerns over how to meet the needs of the current population without endangering the ability of future generations to meet their own needs. Of the three key components that make up the sustainability concept (environment, society and economy), it is environment that has received most attention in the search to find ways forward. In the past many policies have had a purely economic focus, resulting in the externalisation of environmental factors. Consequently in more recent years efforts have been made to internalise these issues. Governments need to deliver on a number of interacting, and sometimes contradictory, policy and societal goals. The search for more sustainable agricultural production provides a classic and key example where there is increasing pressure to improve farming practices to ensure a more sustainable agricultural industry (Lewis *et al*., 2008). Consequently, there are numerous schemes and initiatives that aim to improve the environmental performance of the agricultural industry.

Generally, improvements in the environmental footprint of agriculture are sought by encouraging improvements in farming practices on the ground. The techniques used to deliver this can be broadly divided into three types. The first approach, and probably that most widely used, is knowledge transfer. This includes developing codes of good practice, publishing factsheets and other literature, using informative websites and developing decision support software for farmers (e.g. Green *et al*., 2008; LEAF *et al*., 2002; Chambers *et al*., 2006; Howells *et al*., 1998). The second method uses a range of incentives to encourage voluntary adoption of particular activities. Incentives can vary from special payments such as those offered in return for environmental stewardship, the promise of less government intervention in order to engage industry wide involvement in, for example, the Voluntary Initiative (a package of measures that aims to achieve the environmental benefits sought by Government as an alternative to an imposed tax or charge) (Kidd, 2002; Garratt & Kennedy, 2006) and improved marketing opportunities and consumer confidence via membership of a primary production assurance scheme such as LEAF Marque (LEAF, 2007). Finally, the regulatory approach may be used and examples of this include the regulations introduced to enable the demands of the Nitrate Directive (EEC, 1991a) and the Water Framework Directive (EEC, 2000) to be met.

Another way to consider such methods is to take a very different perspective and broadly classify them into those that are whole farm and those that are targeted measures. Whole farm approaches are typically methods that take a holistic perspective of the farm covering multiple issues that are often integrated. Some have a defined set of rules, others adopt a more general philosophy and some combine both. These include, for example, initiatives such as organic farming, primary production assurance schemes and Integrated Farm Management. Targeted measures tend to focus on specific problem areas on the farm, either in terms of an environmental issue or a single farm activity. Many of these initiatives are driven by regulatory requirements, while others are driven by industry or consumer demands. The Voluntary Initiative (Kidd, 2002), the Action Programme on Nitrate Vulnerable Zones (OPSI, 1998), Environmental Stewardship Schemes (Natural England, 2008a, 2008b, 2008c) and the Agricultural Waste Plastics Initiative (AWSF, 2006) all fall into this category.

Regardless of the techniques used they all predominately concentrate on improving practices to deliver the desired policy outcomes (e.g. safe food; improved health, safety and welfare for workers; improved animal welfare; improved soil, water and air quality; improved or maintenance of biodiversity, etc.) which provide benefits for people and the environment. This relies on there being a thorough understanding of the relationship between practices and outcomes. However, attributing environmental outcomes to specific farming systems and/or activities is not an easy task. As Parry *et al*. (2006) highlighted a number of different initiatives are likely to be operating concurrently on most farms, so ascribing observed environmental effects (positive or negative) to any particular one in isolation is not straightforward. For example, in relation to pesticide use, farming practices could be influenced simultaneously by the 'Green' pesticide code of practice (Defra, 2006), the Voluntary Initiative (Kidd, 2002), Catchment Sensitive Farming (Defra, 2009a) and the EU-wide review on pesticide active substances (EEC, 1991b). These will have a combined effect on the crop protection decisions taken on the farm. Thus attributing any quantifiable environmental outcome to a specific initiative or even identifying the dominant one is very difficult. Additionally, in many instances we may only have simple measures or indicators on which to base judgements of cause and effect. The methods of measurement and assessment in themselves can be problematic and as van der Werf *et al*. (2007) have highlighted different techniques can substantially alter the picture of the environmental impact of a farming system. It should also be noted that implementation of a particular scheme or initiative does not necessarily result in impacts being avoided or mitigated. Thus it is important to assess what the likely impact of any particular intervention will be or has been, in order to determine its effectiveness. Consequently, it is essential that the relationships between causes (agricultural activities) and end impacts (environmental outcomes) are identified.

There are a wide range of techniques that can be used for evaluating environmental impacts (which have been previously applied and critiqued) including environmental risk mapping (e.g. Lahr, 2006), Life Cycle Assessment (LCA) (e.g. RSC, 2010), Environmental Impact Assessment (EIA) (e.g. Wood, 2003), Strategic Environmental Assessment (SEA) (e.g. Smith and McDonald, 1998; Tzilivakis *et al.*, 1999) and the use of environmental indicators (e.g. Hammond *et al*., 1995) for example. Many of these have been applied to agriculture. Christensen (2006) used EIA to evaluate livestock systems and Assimakopoulos *et al*. (2003) used GIS systems to map the risks to agricultural soils from the improper use of N-fertilisers. LCA has been used in several studies comparing agricultural systems (Brentrup *et al*., 2004; Cederberg, 2002; Cederbergy & Mattsson, 2000). There has also been considerable use of environmental indicators, for example, Lewis and Tzilivakis (2004) utilised a suite of environmental indicators to monitor the sustainability of a farm, Bockstaller *et al*. (1997) used ecological indicators to evaluate a range of farming systems and Schloter *et al*. (2003) used indicators to assess soil quality.

Whilst such processes have been used in agriculture for specific studies, particularly with respect to the risk of using agricultural pesticides (Green *et al*., 2008; Tzilivakis *et al*., 2004; Tzilivakis *et al*., 2005; Finizio & Villa, 2002), they have not previously been used to identify the contribution any individual activity makes towards an environmental outcome or for prioritising activities in order to ensure maximum benefits are realised. In order to do this a process of mapping activities to outcomes would be required. Most traditional techniques used for evaluating environmental impact do have embedded processes for identifying environmental effects/impacts and these range from very simple methods such as the use of checklists to increasingly complex procedures including the use of impact matrices to cross-reference activities to environmental components, network diagrams to illustrate linkages and prioritise effects in a system and the use of mathematical models to predict the fate and transport of pollutants.

Determining environmental impact endpoints and the causal processes between activities and endpoints, are key challenges involved in any environmental assessment. These challenges are not new and are not just confined to the impact assessment process. In describing the linkages between stressors and impacts Figure 1 has been used by both Cheung (1994) and Johnson (1993) to illustrate effect chains and orders of impacts.

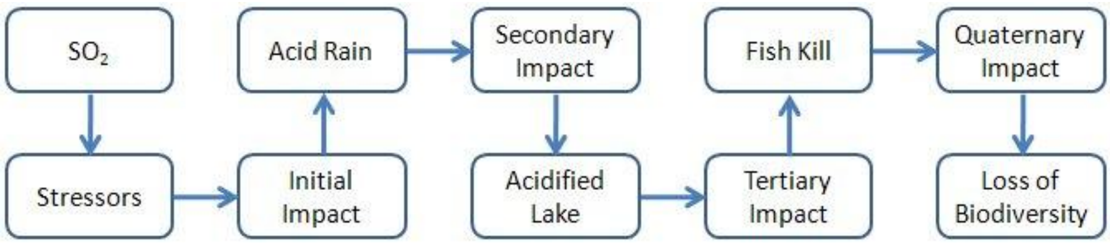

Figure 1. Effect chains and orders of impact (adapted from Cheung, 1994; Johnson, 1993).

This approach enables the conversion of an environmental burden (sulphur dioxide (SO_2) in the example above) into an end impact. The diagram is a very simplified representation of the complex processes occurring in the real environment and therefore it is only possible to identify potential impacts as opposed to guaranteed ones. The potential for further complexity is also highlighted by Guinee *et al*. (1993) who point out that feedbacks are possible within one effect chain or between different effect chains.

Identifying the causal processes and pathways is not just useful for environmental impact assessment as such approaches have also been used for land use studies, particularly in developing countries (Cardoso *et al*., 2001; Verbist *et al*., 2005), to aid the diagnosis of problems and identify intervention points. More advanced causal chain techniques have also been employed in policy analysis, often in combination with indicators (Ewert *et al*., 2009).

This paper reports a novel technique for identifying how different practices and activities influence desirable environmental outcomes. Whilst the method was developed to answer specific agri-environmental policy questions it has been based upon traditional environmental impact assessment techniques and is equally applicable to other systems and processes, and as such it contributes to wider discussions on environmental assessment. The method is presented in the context of agricultural production in the United Kingdom and Europe.

1. Approach Description

The method proposed sought to capture and structure knowledge collated from documented evidence identifying the causal processes by which different activities influenced desirable outcomes. However, understanding that a relationship exists between an activity and an outcome is useful but it does not indicate the significance of that relationship. Therefore, this knowledge was weighted according to its ability to influence the desired outcome using expert opinion. This provided a weighted pathway from activity to outcome and the weakest point in the chain was used to describe the significance of the relationship. This is broadly similar to the use of impact matrices and network diagrams but such processes do not tend to capture the intermediate stages (i.e. the secondary and tertiary effects). Without this information it is not possible to fully understand the cause-effect chain and opportunities for more effective management may be overlooked. The weighting process may also identify effects and outcomes that might otherwise be missed.

Initially, a literature review was undertaken to identify the knowledge associating activities with outcomes and this was captured in a database, which linked together Activities, Effects and Outcomes (the 'AEO database'). Structuring knowledge in this way provided a flexible format for interrogating the information in either a 'top-down' or 'bottom-up' way, as shown in Figure 2.

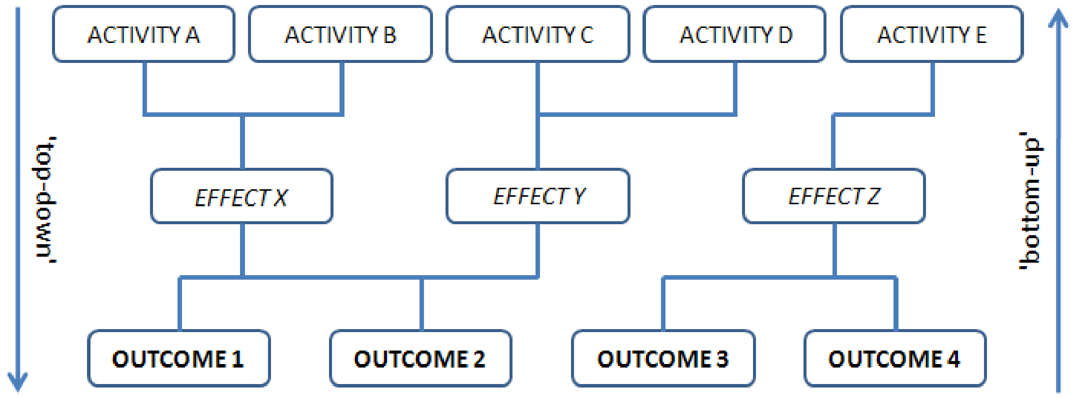

Figure 2. Pathways between activities, effects and outcomes**.**

The database structure is relatively simple. Each component in the cause-effect chain is given a unique identification number and classified as an activity, effect or outcome. An example is given below in Table 1. A second table is used to store the details of the links, i.e. where component 'A' links to (causes) component 'X' (see Figure 2) and information that characterises the significance of the link. Each link in the database is given a weighted value between –10 and +10. Negative values indicate a negative or undesirable relationship between two components whereas a positive value indicates a beneficial relationship. A weighting value of 10 implies a highly significant, strong and well established relationship and 1 means a weak and vague relationship. A third table in the database is used to record a bibliography of the evidence utilised for developing the database and this is cross-linked via the unique identifier such that all activity-effect-outcome chains have their supporting evidence documented.

Table 1

Example of data structured for the AEO database.

ID	**Component name**	**Type**
34	Calibrate fertiliser spreader used on arable land	Activity
35	Accurate application of nutrients to arable crops	Effect
1	Decrease consumption of non-renewable energy sources	Outcome
2	Efficient use of resources (energy)	Outcome
13	Efficient use of resources (nutrients)	Outcome
483	Improved groundwater quality (chemicals – nutrients)	Outcome
487	Improved surface water quality (chemicals – nutrients)	Outcome

The captured knowledge within the AEO database is then used in a 'novel' way to generate a scored activity-outcome impact matrix using software developed specifically for the purpose. The database interrogation software operates either top-down or bottom-up (see Figure 2) retrieving all the appropriate links from its start point to the end of the chain. This is illustrated in Figure 3. The size of the arrows in the diagram, reflect the significance of the link between the two components.

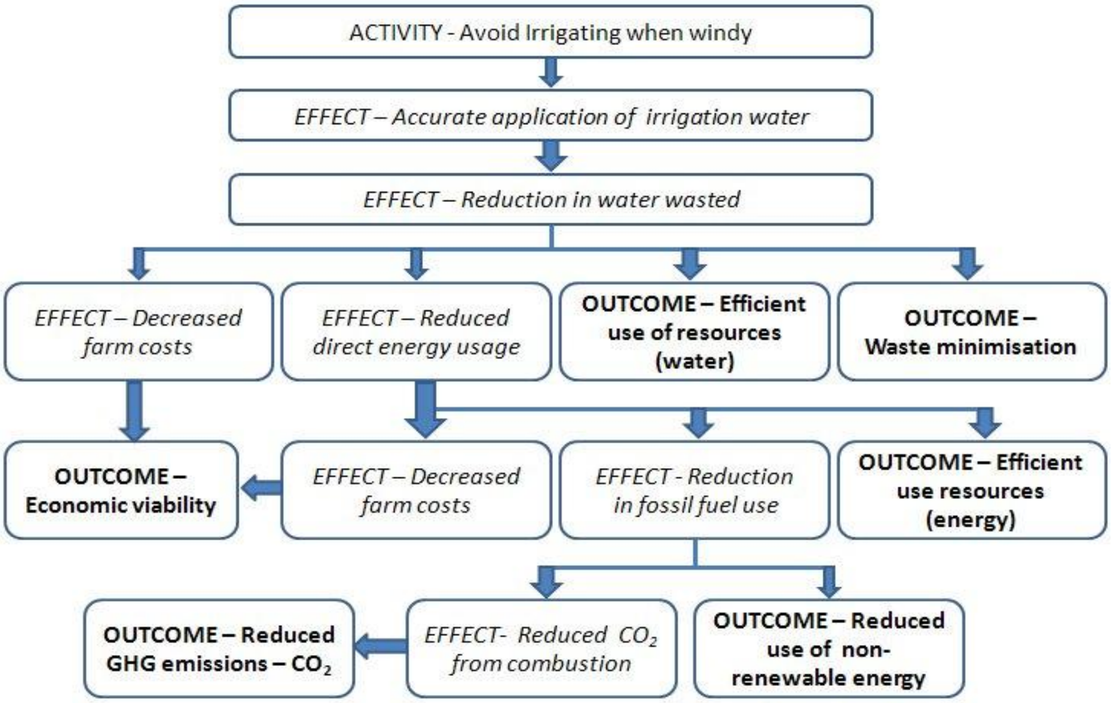

Figure 3. Example top-down interrogation using the AEO database.

A 'weak link' approach is taken for generating a final score describing the relationship between a particular activity and an associated outcome, this uses the premise that the cause-effect chain is only as strong as its weakest link. The weighting values along each chain are examined and the lowest is selected to reflect the score for the overall relationship between an activity and an outcome. An alternative approach would be to average the scores along the chain but this can hide weak links and thus does not reflect the true strength of the causal relationship. For example, if a chain had 3 links with weighting values of 10 and one of 2, the average would be 8, whereas the 'weak link' approach scores it as 2, thus reflecting that at one point in the chain there is a weak relationship. The 'weak link' approach also works well for highlighting strong chains. For example, where there are a clear set of well established, properly understood and significant processes between an activity and an outcome each would obtain a high weighting value. Therefore the overall score (i.e. the lowest weighting value in the chain) will be high as all intervening values are high. In some instances a single activity may have multiple 'pathways' by which it can influence the outcome. Where this happens the final scores for the multiple pathways are averaged. The calculation reasoning becomes more complex where the chain of events includes double or multiple negatives. In these instances the weak-link system is still valid for identifying the chain overall score but further assessment to identify the end benefit or burden of the chain must be determined. Considering Activity E in Figure 4 the end outcome of the chain is positive because the proceeding events reduce the negative impact. Figure 4 illustrates the process of generating activity-outcome scores from activity-effect-outcome chains. When this process is undertaken for all activities for all outcomes, it results in the creation of the aforementioned activity-outcome impact matrix.

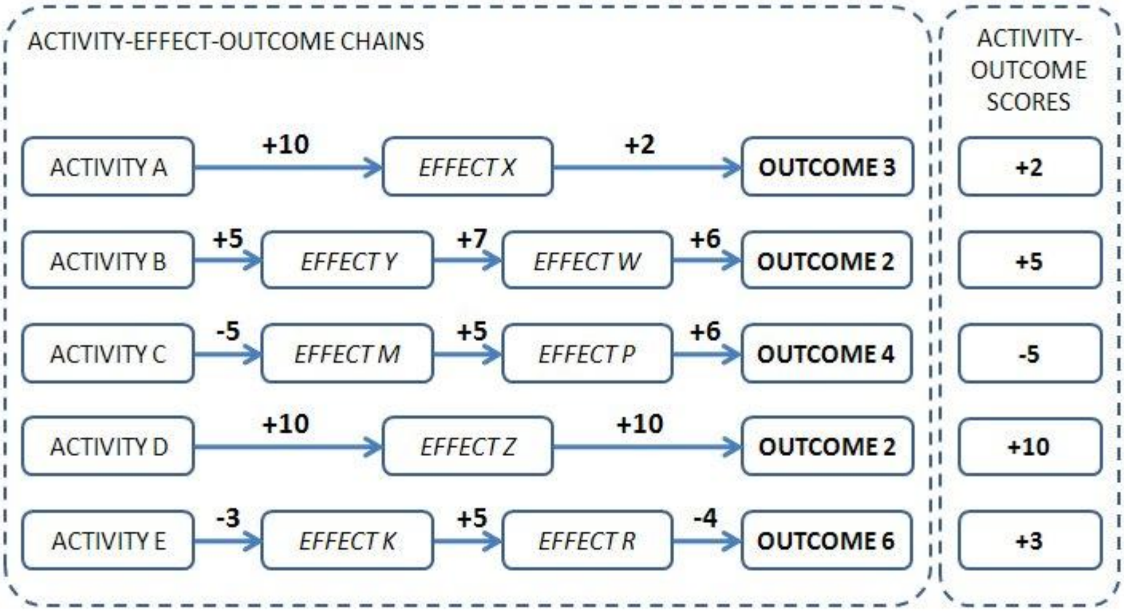

Figure 4. The process of generating activity-outcome scores from effect chains.

The approach can be taken a step further so that the contribution of a suite of activities within a specific initiative, such as a primary production assurance scheme or an environmental stewardship scheme, makes towards a particular outcome can be evaluated. This is done by calculating the total score across all activities contributing to the outcome and expressing this as a percentage of the maximum possible. For example, consider Initiative A which has five Activities which contribute to Outcome X. The total score for these five Activities is +35. Within the AEO database there may be a total of 65 Activities which have been identified as contributing towards Outcome X and the total score for all 65 Activities is +318. Therefore the total contribution Initiative A makes towards Outcome X is 35 out of a maximum of 318 or 11%. However, the results can be tailored further such that any activity which is irrelevant to a particular farm can be removed from the calculation. Using the example above, if 20 of the original 65 Activities were related to livestock farming but the farm was purely arable with no livestock, these 20 Activities are omitted and the total score for the remaining 20 Activities becomes +219. Therefore the total contribution Initiative A on this particular farm makes towards Outcome X is 35 out of a maximum of 219 or 16%.

This methodology can then be extended to calculate the net contribution a single initiative is having on a farm when the farm is involved in a number of initiatives simultaneously. First the total contribution being made to a particular outcome, considering all activities undertaken when all initiatives are in place, is calculated. Then the contribution is recalculated with the initiative of interest removed. The difference between the two contribution scores can then be attributed to the initiative of interest. This is explained further in section 3.2 below.

2. Application examples

2.1. Evaluating the contributions of single initiatives to policy outcomes

Using the methodology described above the contribution three different initiatives make towards a range of desirable agricultural policy outcomes has been calculated (Table 2) and presented as the percent contribution of the maximum possible. For simplicity the outcomes as displayed are actually 'outcome groups' where individual specific outcomes have been grouped together to deliver a broader objective. For example, 'Resource efficiency' includes the efficient use of energy, water, nutrients, pesticides and other farm inputs (the agricultural AEO database actually contains 64 outcomes in total that have been collated into 18 groups). The three initiatives considered are:

- LEAF Marque (LM) a primary production assurance scheme which has the overall objective of encouraging the adoption of more environmental sound farming methods;
- The Action Programme for Nitrate Vulnerable Zones (NVZs) which is a suite of regulations farmers within certain designated areas must comply with in order to protect water bodies from nitrate pollution;
- The Voluntary Initiative (VI) which is a programme of measures, agreed with Government, to minimise the environmental impacts of pesticides particularly with respect to water quality and biodiversity.

Table 2

Outcome assessment results for example initiatives.

	OUTCOME contributing towards improving…..																	
Initiative	Air Quality	Animal health & welfare	Biodiversity	Biosecurity	Carbon sequestration	Countryside access	Farm economics	Resource efficiency	Energy efficiency	Food safety	Food security	Greenhouse gas emissions	Landscape and heritage	Public safety	Soil quality	Waste and recycling	Water quality	Worker health & Safety
LM	0	0	47	0	30	23	21	42	12	12	33	24	28	26	20	25	40	9
NVZ	7	0	11	0	5	0	4	20	6	2	8	10	0	0	0	16	18	0
VI	0	0	12	0	8	0	8	4	3	10	23	2	4	12	12	10	12	16

With respect to LEAF Marque the outcome assessment clearly reflects the Schemes objectives and shows that it is making significant contributions towards a range of environmental outcomes including improving biodiversity, carbon sequestration, resource efficiency and water quality. It should be remembered, however, that with respect to national policy the results herein need to be considered in conjunction with other factors such as the area farmed under LEAF Marque compared with the total farmed area.

Considering the outcome assessment for the Action Programme for Nitrate Vulnerable Zones the results are a little more surprising. Whilst the overall objectives of the regulations are to protect surface and groundwaters from nitrate pollution a number of other policy benefits are being achieved. These include benefits for biodiversity and resource management arising from improved nutrient management. More optimal use of nutrients also has positive consequences for greenhouse gas emissions as reduced usage results in lower emissions of nitrous oxide, directly during farm application and indirectly from their manufacture.

There is a similar story with the Voluntary Initiative with benefits going beyond that of protecting water quality and biodiversity. For example, policy contributions are obtained for food safety as improved use and management of pesticides will reduce the risk of pesticide residues in fresh food produce. Benefits for food security are realised as more efficient use of pesticides will improved crop yields and reduce farm costs improving business viability.

2.2. Use of the technique to inform policy

As previously discussed, it is often the case that a farm will be involved in several initiatives simultaneously and it is, therefore, very difficult to attribute specific benefits to any single initiative in isolation. For example, the LEAF Marque (LM) assurance scheme is always conducted in conjunction with a more main stream assurance scheme. On a farm producing fresh vegetables this is likely to be Assured Produce (AP). The farm will also need to be compliant with the Cross Compliance regulations (XC) (Defra, 2009b). The technique described herein can be used to identify the net benefit of, for example, the LEAF Marque when it is used alongside other initiatives. Table 3 shows the total percent contribution of the maximum possible for (1) all activities within LEAF Marque, Assured Produce and Cross Compliance and (2) all activities within the Assured Produce and Cross Compliance. The net benefits from LEAF Marque on this particular farm are the difference between the outcome scores (1) and (2).

Table 3
Calculating the net benefit of a specific initiative.

	OUTCOME contributing towards improving…..																	
Initiative	Air Quality	Animal health & welfare	Biodiversity	Biosecurity	Carbon sequestration	Countryside access	Farm economics	Resource efficiency	Energy efficiency	Food safety	Food security	Greenhouse gas emissions	Landscape and heritage	Public safety	Soil quality	Waste and recycling	Water quality	Worker health & Safety
LM+AP+XC	14	0	72	0	31	47	47	44	12	81	56	19	54	34	56	35	61	40
AP+XC	14	0	58	0	16	32	36	38	8	69	37	19	42	24	43	26	44	40
LM NET	0	0	14	0	15	15	11	6	4	12	19	0	12	10	13	9	17	0

3. Discussion and Conclusions

The examples used herein to illustrate the technique show that it appears to work well. However, it is not without its limitations. Probably the main issue is the population of the AEO database. For the application of agriculture, for which the method has been piloted, providing sufficient data for the system to work adequately was an ambitious task and the database currently contains around 850 data components and 1200 links. The resulting activity-outcome matrix consists of a table of approximately 64 outcome columns by 500 activity rows. It is also something that will never be complete as our knowledge is continually advancing and so the database will need to be maintained. Due to the resource implications of building such a knowledge base the 'weak link' approach is not suitable for ad-hoc environmental impact assessments studies. However, once such a database has been built it provides an extremely powerful and valuable resource that has a multitude of applications particularly for understanding the impacts of policy. As the knowledge grows its power and potential will increase. Even at its simplest level the process of formally creating activity-effect-outcome chains with supporting documented evidence is a valuable contribution to holistic environmental impact assessment.

The success of the 'weak-link' approach does rely on the weighting process and this is undoubtedly subjective. Such subjectivity is a common issue across many techniques used to identify environmental effects. Consequently, care and a structured, formalised approach to assigning weighting values to the linkages must be taken. The approach adopted was deemed the best as it was not overly complex and worked well with the structure of the AEO database.

Despite these limitations, it is considered that the techniques described within this paper provide a valuable step forward in aiding environmental impact assessments (EIAs, SEAs, LCAs, etc.), particularly with respect to large processes and systems where there are a multitude of interacting environmental effects. In a policy context, the outcome-based approach aligns well with focusing on providing benefits to people, by placing impacts in the context of real benefits to stakeholders. Additionally, the ability to focus on activities that have the greatest influence on end outcomes could aid the development of more cost-effective policies, which is an additional benefit to wider society. The approach also has the potential to be used within environmental management systems more generally (Tzilivakis et al., 2009). It can provide a means of evaluating the performance of the activities of an organisation (using a top-down analysis of the organisations activities) and identifying potential activities that can be implemented to address specific outcomes (using a bottom-up analysis), all within the context of a cycle of continuous improvement.

The approach provides a very holistic perspective that is essential for understanding sustainability issues. In many respects it is a 'broad and shallow' approach and it could be argued that it lacks the deeper and finer detail required for other types of environmental assessment. For example, it does not quantify emissions like the inventory phase of a life cycle assessment. However, this does not mean that such detail cannot be added where necessary, to convert a 'broad and shallow' view into one that is 'broad and deep'. Alternatively, the approach can be used to add a wider perspective to more focused studies. For example, it could be used to compliment a study quantifying greenhouse gas emissions, so that wider impacts can also be considered alongside the more detailed quantitative information. There is also potential to use the technique as part of the scoping phase of any environmental impact assessment, to determine the key activities and impact areas that need to be quantified or studied in more detail.

There are many different methods, systems and techniques that can be employed to undertake an environmental assessment. Common to all of them is the need to distil what is often complex knowledge into a format that can be used to aid the decision making process. The broad horizons of sustainable development demand that a holistic perspective be taken, therefore the amount of knowledge that needs to be distilled is large and constantly expanding. Consequently it is important that we explore techniques that can capture and structure this knowledge to aid those making decisions that will affect future generations.

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