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Including natural resource management and environmental impacts within impact assessment studies: methodological issues

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Including natural resource management and environmental impacts within impact assessment studies: methodological issues

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Centre for International Economics

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Foreword

It is well known that agricultural systems both influence, and draw on, the natural environment. The same is true for the impacts of agricultural research and development (R&D). Through its effects on production systems, or on policies regarding the environment, agricultural R&D can potentially have a range of natural resource management or environmental impacts.

To date, impact evaluations of R&D have largely focused on agricultural systems; appraisal and valuation of environmental and ecosystem impacts of R&D have been less common. This is largely because valuing environmental and natural resource impacts of agricultural R&D involves substantive empirical challenges. Nevertheless, the Australian Centre for International Agricultural Research (ACIAR) is interested in understanding the full range of impacts of the R&D it funds.

If the evaluation of environmental impacts is to be meaningful, particularly when planning new research activities, it is important wherever possible to place the environmental impacts on the same basis as other measured impacts—and ideally these involve monetary values commensurate with those from broader economic impacts. This report provides an overview of the methodological issues involved in incorporating environmental and natural resource values within ACIAR's economic impact assessments.

As the report points out, recent developments in analytical techniques have provided a sound basis for combining two parallel streams of research: traditional economic analysis of the environment (including a range of specialist techniques) and the 'ecosystem service' approach to evaluation. These recent developments have served to clarify the ways in which the core ideas of ecosystem services can be applied within a consistent evaluation of R&D impacts.

In the context of this report, the authors define these two approaches as essentially complementary; each adds something that is missing from the other, leading to an overall view that is both descriptively useful and analytically sound. They conclude that R&D evaluation requires a particular use of the ecosystem service concept, which gives a value to the increment in ecosystem services resulting from the complex chain of actions associated with the adoption of new knowledge, techniques or capacity generated through agricultural R&D. This thinking brings an added dimension to measuring the benefits attributed to ACIAR-funded research.

Nick Austin
Chief Executive Officer, ACIAR

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Summary

The challenge

It is no surprise to those involved with agricultural research that agricultural production (including downstream processing) affects the environment and that the environment provides essential inputs to agricultural production. This relationship is broadly summarised in Figure 1, which uses the ideas of ecosystem services to illustrate the inputs to, and the positive and negative outputs from, agricultural systems.

This report considers how to incorporate the effects of agricultural research and development (R&D) on environmental outcomes within the impact assessments regularly undertaken for research funded by the Australian Centre for International Agricultural Research (ACIAR). In particular, the report is concerned with evaluating environmental outcomes using an economic surplus framework, consistent with that currently used for ACIAR impact assessments. Effectively, this means using an extended cost–benefit framework and grounding values within a 'willingness to pay' conception of economic welfare analysis.

Two challenges arise in this regard: first, satisfactorily identifying the environmental impacts of the agricultural R&D; and second, finding empirical methods for evaluating these impacts (that is, deriving willingness to pay) given that many of them are not mediated through market transactions.

Two streams of analysis

The assessment of environmental impacts of R&D can be undertaken by drawing on two broad streams of analysis: the traditional economic approach to environmental evaluation, and the ecosystem service approach to identifying interactions between agriculture and natural systems. These two approaches are complementary, and recent research has further shown how they can be combined to provide powerful analysis of environmental interactions.

The economic approach teaches that there are many values associated with environmental inputs and outputs, and that only some of them are captured in market transactions. Economic analysis in this field is (in part) concerned with identifying tools for deriving values from goods and services where explicit market transactions are absent. This is in contrast to much impact assessment in which a range of (possibly distorted) market prices often forms the basis of the analysis.

The concept of ecosystem services—along with the various taxonomies that have been developed—provides a cogent way of thinking through the interactions between human systems (and ultimately human values) and the natural resource base on which these systems draw.

Recent analysis of ecosystem services from an economic perspective has indicated how to use the powerful underlying ideas while avoiding double-counting of values.

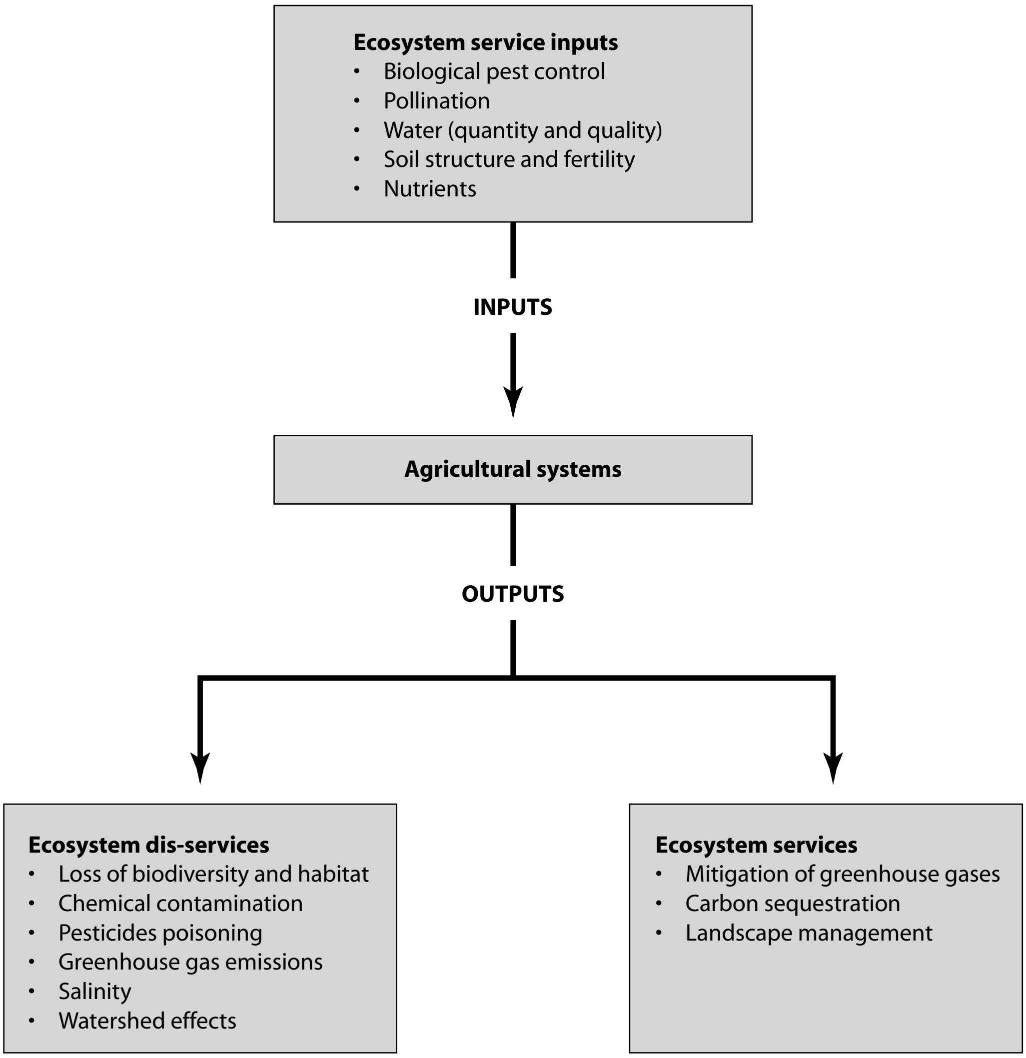


Figure 1. Agricultural ecosystem inputs and outputs. Source: Centre for International Economics, based on Power (2010).

The economic analysis of non-market transactions, and appropriate identification of ecosystem services, thus provide a natural combination for thinking through the broader impacts of agricultural R&D.

Thinking through R&D impacts

Figure 2 identifies seven potential impacts of agricultural R&D on ecosystem services. The logic of Figure 2 is to identify where—in the conceptual process of moving from ecosystems to human wellbeing—agricultural R&D could have an impact.

Agricultural R&D can potentially affect outcomes and information at each step in the causal chain linking basic ecosystems to human values (as further described in Table 1).

As is usually the case, these impacts need to be evaluated relative to the 'business as usual' or 'without R&D' scenario. This means that the relevant impacts may be positive or negative, depending on the context within which the research is taking place.

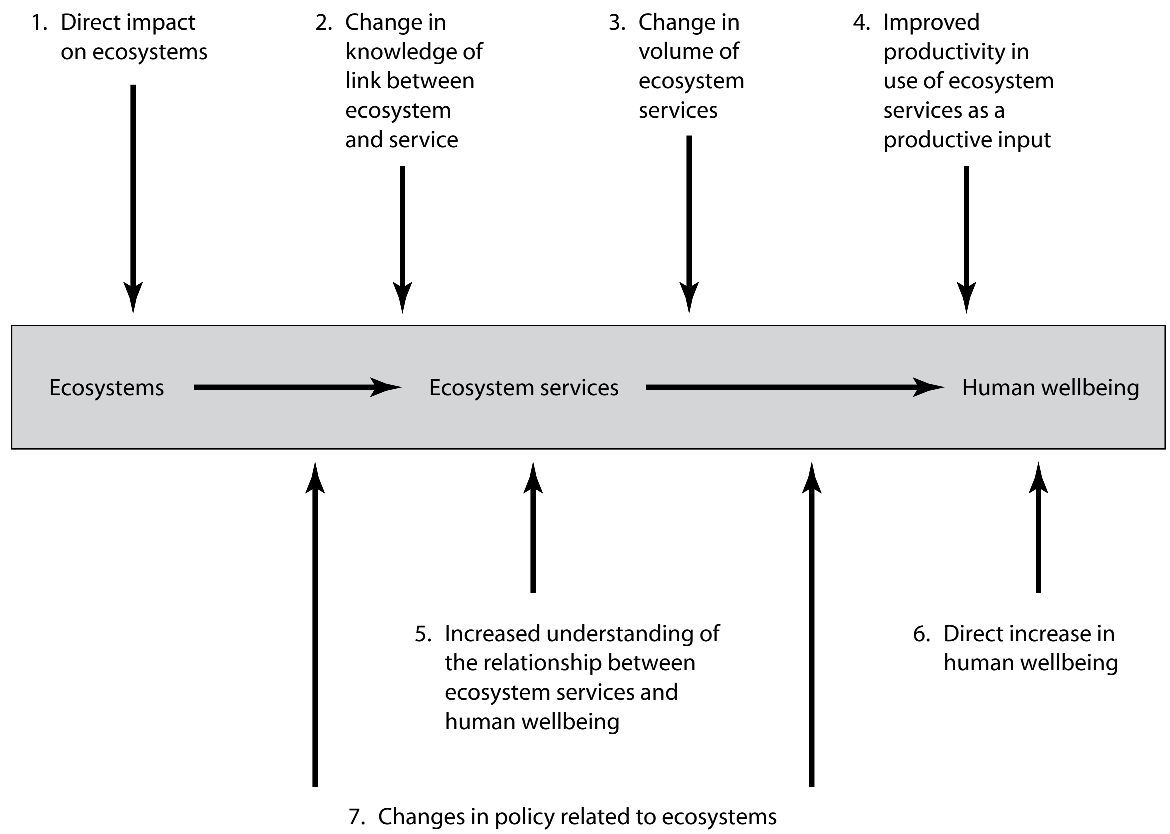


Figure 2. Categories of agricultural R&D impacts on ecosystem services. Source: Centre for International Economics.

Application to impact assessment

One of the major challenges in assessing the impact of R&D on environmental outcomes, aside from properly understanding the biophysical interactions involved, will be to satisfactorily value the impacts.

Evaluation of non-market impacts requires specialist analysis and can often be time consuming and costly. This report proposes a procedure—based on careful use of 'benefit transfer' from existing studies—to determine whether specialist valuation will make a significant contribution to understanding the underlying benefits of the project(s) being evaluated.

This essentially involves comparing the order of magnitude of environmental benefits (derived with careful use of benefit transfer) with other benefits of the project.

ACIAR projects and environmental impacts

A desktop review of ACIAR projects considered to have some degree of natural resource management or environmental impact indicates that impact 4 in Table 1 (improved productivity in the use of ecosystem services as an input) is the most frequent type of impact (Figure 3).

The second most frequent is impact 3 (a change in the volume of ecosystem services available for human welfare) followed closely by impact 7 (policy).

Table 1. Potential impacts of R&D on ecosystem services

Impact	Description
Impact 1. Impact of changes induced by R&D on underlying ecosystems themselves.	For example, decrease in emissions of various kinds (smoke, chemicals, processing effluent) may directly affect functioning of ecosystems. Reduced withdrawal of resources from ecosystems (water, for example) will affect ecosystem function.
Impact 2. Change in knowledge about the relationship between underlying ecology and potential ecosystem services.	The relationship between ecosystems and potential ecosystem services is complex. R&D may improve basic scientific understanding of these relationships.
Impact 3. Change in the 'volume' or 'quality' of ecosystem services.	Increase in the volume of the ecosystem services (such as increased carbon sequestration) may result from production changes related to R&D.
Impact 4. Improved productivity in the combination of capital and other inputs with ecosystem services.	Increased production efficiency in the use of ecosystem services may result in releasing environmental resources for other uses.
Impact 5. Increased understanding of the relationship between ecosystem services and human wellbeing.	The link between ecosystem services and human wellbeing is an issue of ongoing scientific exploration.
Impact 6. Direct increases in human wellbeing.	Reduced emissions of various kinds may directly improve human wellbeing (reduced smoke, for example).
Impact 7. Changes in policy broadly relating to ecosystems.	Institutional structures and policies have a direct influence on the full ecosystem service chain.

Source: Centre for International Economics

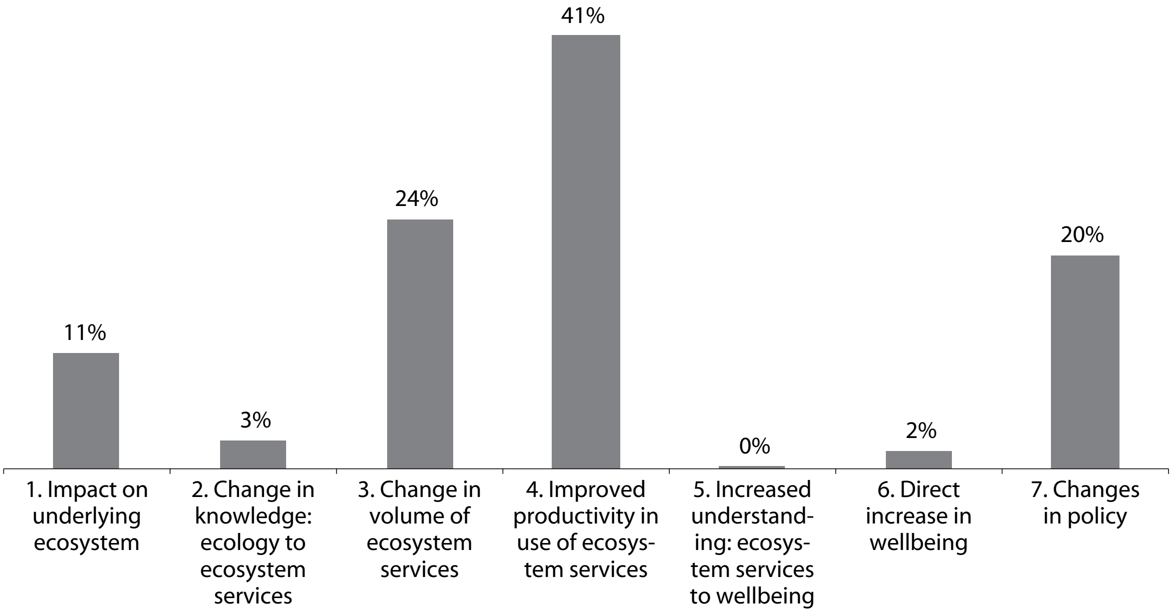


Figure 3. Frequency (share of total) of impact categories. Data source: Centre for International Economics' estimates based on ACIAR project documents.

1 Introduction

Background

Farming systems both use and influence natural resources …

Farming systems (and their associated value chains and markets) are very closely linked with ecological systems and draw extensively for their productivity on a base of natural resources. These resources range from the microscopic ecosystems within the soil, to the watershed systems that feed into farms, to the range of organisms that provide services such as pollination.

The linkages work both ways, and farming and agricultural processing can often have a substantive influence on environmental and ecosystem outcomes. Different farming methods can enhance, or detract from, the natural resource base that the methods ultimately draw on.

… as does agricultural research and development

In its aims to improve the productivity of farming systems, agricultural research and development (R&D)—once adopted in some form—can also have a direct or indirect impact on environmental outcomes. Environmental effects may be the side effect of other changes induced by R&D or they may result from R&D targeted at natural resource management and environmental issues.

While current impact evaluation of R&D mostly accounts for, and values, the *economic* impact of R&D, accounting for and valuing the environmental and ecosystem impact of R&D is less common.

However, in most countries—and certainly within the global partnership of the Consultative Group on International Agricultural Research—increasing attention is being paid to the environmental or natural resource outcomes of agricultural research (see, for example, CGIAR (2011)).

Three key questions arise when considering the environmental impacts of agricultural R&D (Figure 4):

- how to identify the relevant R&D outcomes
- how to assess the direct and indirect biophysical effects of those outcomes
- how to value the biophysical effects.

Further, for the evaluation of environmental impacts to be useful, particularly when planning new research activities, it is important that, to the greatest extent possible, the environmental impacts be placed on the same basis as other measured impacts—including (but not exclusively) through the use of monetary values commensurate with those from broader economic impacts.

Substantive empirical challenges

There are several reasons why valuing environmental and natural resource impacts of agricultural R&D involves substantive empirical challenges:

- In many cases, valuation will involve dealing with values that are not explicitly reflected in market prices:
  - interestingly, though, economics has a strong tradition of trying to understand 'shadow values'—and traditional R&D impact evaluation has had to confront the fact that, in many cases and in many developing economies, regulations and other market constraints mean that underlying values are not necessarily reflected in market prices

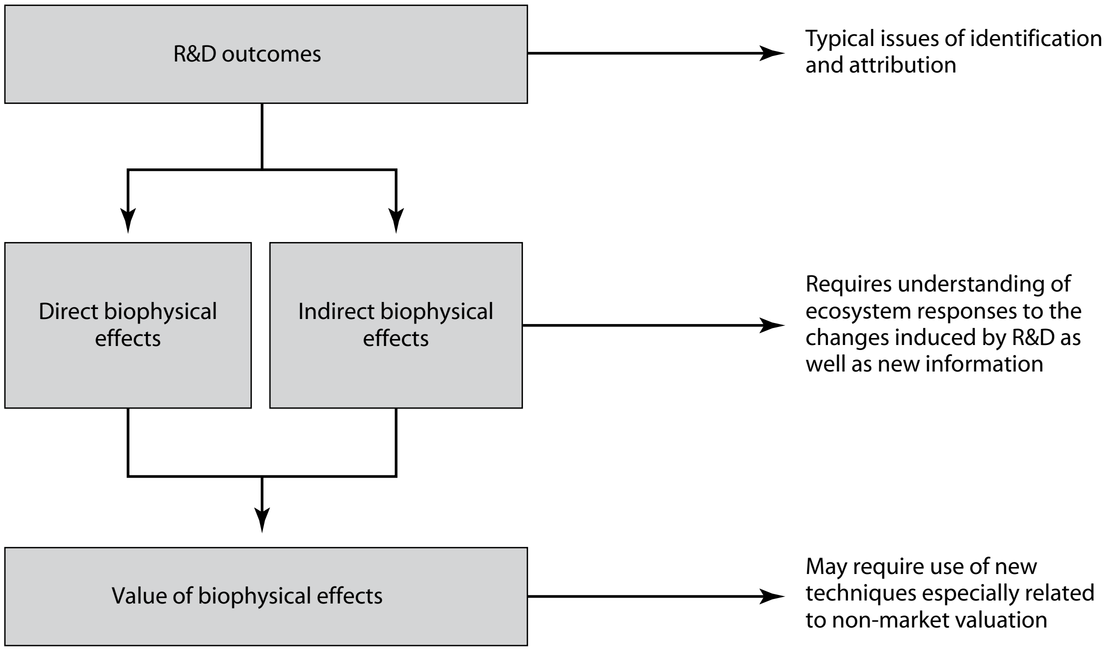


Figure 4. The path from outcomes to impacts. Source: Centre for International Economics.

  - the need to value environmental outcomes without any explicit market prices is in some ways an extension of the challenge posed by distorted markets.

- The 'production function' is considerably more complicated in the case of environmental impacts. In the traditional case of evaluating productivity improvements, for example, the challenge is to understand the way in which the outputs or outcomes from the research intersect with the existing agricultural production functions to create an increase in value for the same level of inputs. In the case of much environmental evaluation, an additional challenge is to understand the 'ecological response' function (or the 'biophysical response' relationship) associated with the R&D.
- Measuring the incremental impacts of R&D (and attributing these to particular research streams), while always a challenge in R&D impact evaluation, may be particularly challenging from the environmental perspective where baseline environmental outcomes are complex, occur in many different dimensions and may involve nonlinear or threshold effects.
- The information base required to assess environmental impacts is more extensive than for traditional economic impact analysis and may involve a range of specialist empirical techniques.

This report

This report provides an overview of the methodological issues involved in incorporating environmental and natural resource values within the economic impact assessments conducted by the Australian Centre for International Agricultural Research (ACIAR), with a particular focus on doing this within an economic surplus evaluation framework. The primary purpose is to draw together research in this area, highlighting the advances that have been made and pitfalls that need to be avoided. It does not purport to be a definitive paper; rather it is hoped that, as work on this important area continues, and as new techniques are developed, the analytical framework presented here will continue to be updated.

A note on terminology

In this report, the terms 'natural resource management' (NRM), 'environmental impacts' and 'ecosystem services' will be used largely interchangeably, although there are some differences in nuance between the three terms. In particular:

- 'natural resource management' conveys a sense of the active management of the natural resource basis that agriculture draws on. R&D in this space may be concerned with actively improving the efficiency of the use of natural resources. NRM thus implies, to a degree, but not exclusively, the use of natural resources as a subject of R&D
- 'environmental impacts' in some discussions conveys a sense of negative impacts on the 'environment', which is in turn conceived very broadly to include processes not directly controlled by humans
- 'ecosystem services' will be defined in more detail below, but essentially involves a broad framework of thinking through both NRM and environmental impacts.

2 General principles: incorporating environmental valuation within impact assessment studies

Extended cost–benefit analysis

The broad framework for analysis covered in this report is concerned with what has been termed 'extended cost–benefit analysis' (see, for example, Bennett (2009, 2011a)). This is essentially cost–benefit analysis of the form typically undertaken within impact assessment but extended to include more generalised valuation concepts related to environmental impacts.

Within extended cost–benefit analysis, the standard disciplines of the procedure remain (clear definition of the 'with' and 'without' R&D scenarios, for example) but the understanding of the welfare implications of particular R&D outcomes is extended to included environmental values.

Maintaining an economic surplus focus

Consistent with this, when including natural resource and environmental impacts within an impact assessment, it is important to make sure this evaluation is consistent with—and can be added to—the traditional measured impacts.

This means that it is important to maintain an *economic surplus* approach when evaluating environmental impacts. This is particularly the case when considering the broad ecosystem service impacts of R&D, where in the past economic surplus has not always been the focus of ecosystem surplus valuation.

'Willingness to pay' the core valuation concept

This surplus approach in turn implies that a core valuation concept needs to be 'willingness to pay' (WTP) from the perspective of the different beneficiaries of the R&D. This creates particular challenges where this WTP cannot be directly inferred from market transactions (in contrast with most traditional impact evaluation where market transactions form the basis of assessments of WTP).

Channels of impact: from R&D to the ecosystem

Figure 5 illustrates that there are essentially four channels of agricultural R&D impact, three of which are specifically concerned with environmental outcomes.

The standard channel: R&D to productivity

The right-hand stream in Figure 5 shows the typical linkages identified and used within standard R&D evaluation. Research outcomes (assuming adoption and so on) lead to improvements at the farm (or processor etc.) level. These may be increases in productivity, reduced costs, improved knowledge, capacity building and so on.

The value of these outcomes is assessed in the light of the basic agricultural production function (the 'shift in the supply curve'); the market in which the farmer (or processor) operates; and changes in prices and

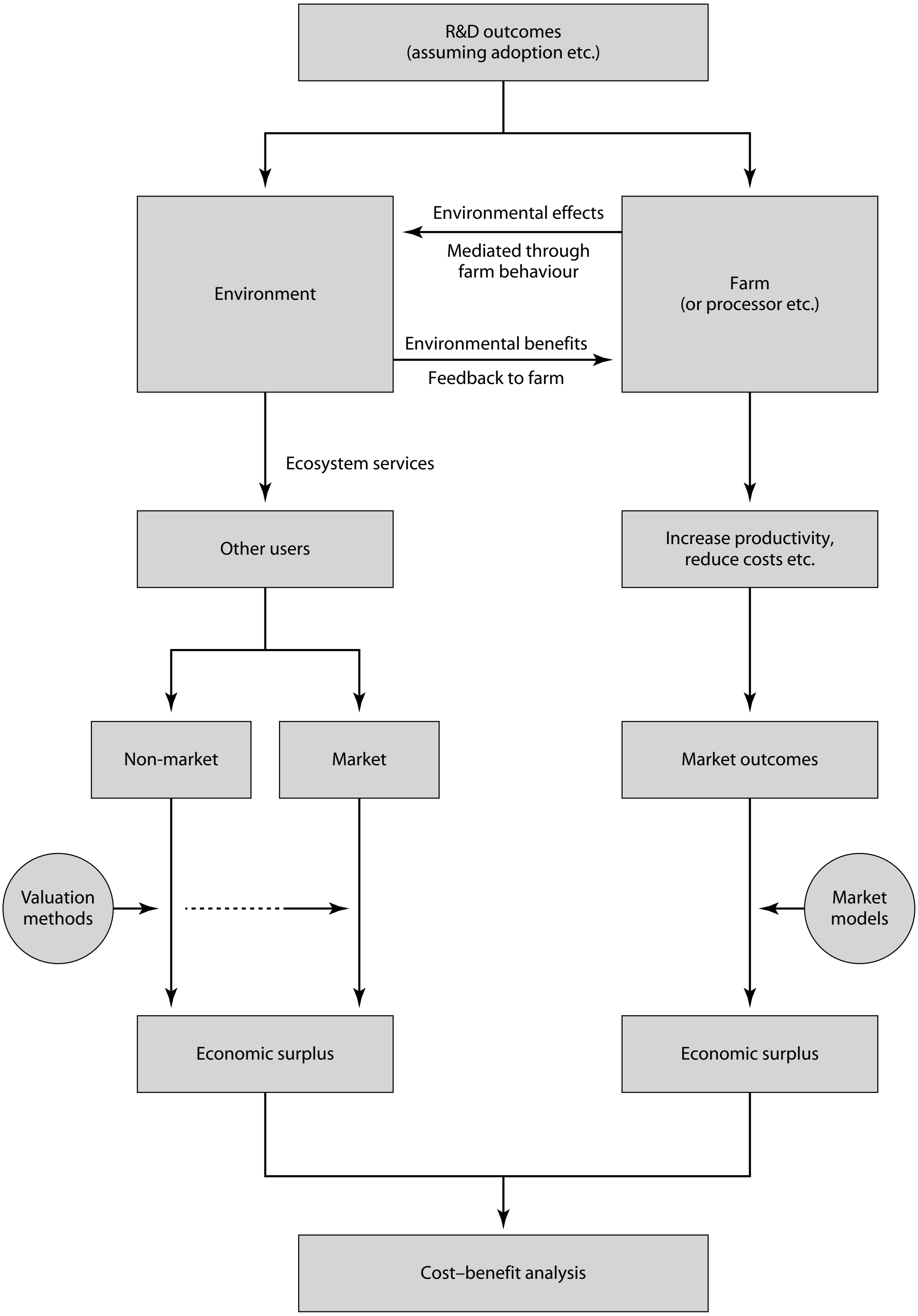


Figure 5. Channels of agricultural R&D impact. Source: Centre for International Economics.

the distribution of effects between consumers and participating and non-participating producers.

Improvements in environmental and resource management outcomes within the farming system

Many of the environmental and natural resource benefits of R&D are likely to lead to improved outcomes *within* the farming system. Improved soil condition, greater efficiencies in the use of water resources, better understanding of nutrient flow and so on, all have direct benefits to the farming system, in many ways similar to the traditional productivity increases typically measured in economic impact analysis.

Indeed, much economic impact analysis implicitly assumes that the environment is accommodating to the new techniques and practices emerging from R&D and so, in many cases, there is already at least implicit environmental evaluation within the analysis.

Environmental benefit mediated through R&D-induced farm behaviour change, with benefits external to the farm

Changed farm practices—implemented for gains on-farm—may have secondary environmental impacts off-farm. These effects, mediated through ecosystem services, affect other agents not necessarily involved in farm activity. These external effects may, or may not, have market implications. Indeed, in most cases there will be no market interaction involved, and so the evaluation of the impact will need to use a range of non-market valuation techniques.

Direct improvements in environmental outcomes

Some agricultural R&D may lead to direct improvements in environmental outcomes without necessarily involving behaviour within the farming system, although this will clearly involve behavioural change in adoption of R&D findings somewhere within the economy.

Multiple channels for particular R&D

It is highly likely, of course, that adoption of some agricultural R&D will have environmental impacts through more than one of these channels.

Positive effects, or avoiding negative effects

As is always the case, understanding the baseline (or the without-research scenario) is crucial in framing R&D impacts. This may involve baseline improvements in environmental and natural resources outcomes, or the avoidance of ongoing negative impacts. In traditional impact evaluation, these different variations to baseline are often symmetric—shifting a supply curve back, or moving it down by the same vertical amount (at least with linear demand and supply curves), has the same value implication. With environmental outcomes, this will not always hold and the choice of valuation technique may depend on the direction of effect.

Geographic extent of effects

These various channels of effect may take place at a range of geographic levels: within a single farm, between farms within a particular region, or extending well beyond the original farming region influenced by the R&D (as illustrated in Figure 6).

The geographic extent of impacts will clearly have a significant influence on the valuation techniques adopted and may itself be related to the nature of the environmental effects of the R&D. Changes in carbon storage (the removal of carbon from the atmosphere), for example, have a global impact (through potential impacts on climate change) while changes in salinity can often have more-local effects (possibly between adjacent farming systems).

Of course, the geographic scope of effects also depends in turn on the geographic scope of the original R&D and its adoption. Research focused on salinity, for example, if adopted widely has scope beyond the original regions involved because of the aggregation of effects involved.

The same is true for air quality effects; although because of the nature of air pollution it is likely that these impacts will be much broader, extending regionally or even nationally.

Water quality effects may be local, regional or even national (in some cases) depending on the nature of the water systems, catchments, hydrology and so on influenced by the adoption of the R&D.

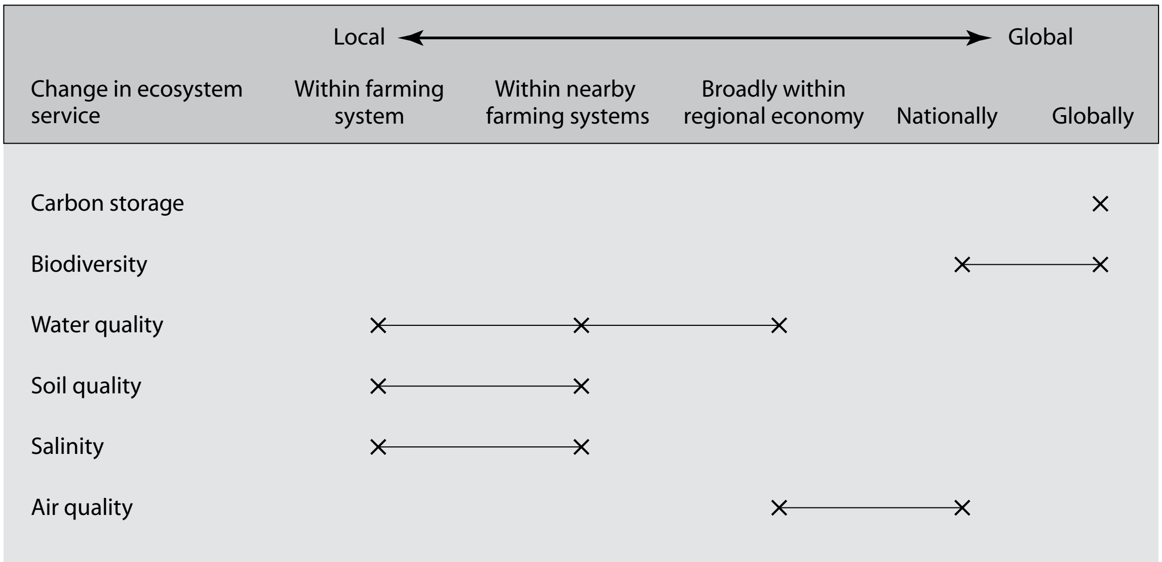


Figure 6. Geographic scope of effects. Source: Centre for International Economics.

Finally, biodiversity effects can potentially be global to the extent that there is widespread WTP for (non-use) values associated with diverse ecosystems.

The type of extended valuation needed

Figure 7 summarises the way in which the valuation of impacts needs to be extended when considering the full range of potential environmental impacts of R&D. The top-left quadrant of the figure is essentially the domain of standard impact analysis, while the remaining three quadrants need to be considered for analysis of environmental impacts.

Figure 7 makes a distinction between 'marketed' and 'non-marketed' outcomes that can occur on- or off-farm. (Note that in this chart the on-farm/off-farm distinction refers to the full farm value chain, thus on-farm includes the farm value chain.)

For on-farm impacts where the effects are mediated through a market, then it is relatively straightforward to use conventional surplus techniques based on market models to assess the impact of R&D. In the case of environmental impacts this is likely to be fairly rare, however.

It is also possible for off-farm environmental impacts to be mediated through markets. Carbon markets are a good example of this, as their scope and extent is steadily (but haltingly) increasing. Some agricultural R&D is concerned with improving carbon uptake in various ways and so can potentially be valued using information from carbon markets (as noted below, however, care needs to be taken when doing this).

The most likely situation, however, is that there will be no explicit markets (or market prices) for either on- or off-farm environmental impacts. For these cases, a range of techniques must be used to assess the economic surplus associated with the impacts of the R&D. These are discussed in more detail below.

Two streams of literature dealing with environmental impacts

There are two, broadly parallel streams of literature that can be drawn on when considering the environmental and natural resource implications of R&D:

- the economic approach (sometimes called 'total economic value') approach to environmental analysis

	On-farm	Off-farm
Marketed	• Can use conventional surplus techniques • Likely to be rare for most environmental effects	• Observe outcomes where markets exist for environmental 'goods' • Likely to increasingly be the case for carbon sequestration
Non-marketed	• Use production function type approach • Need to understand the production relationship between environmental 'good' and farm output	• **Revealed preference** techniques where environmental goods can be linked to other marketed goods (e.g. travel cost method, hedonic pricing) • **Stated preference** techniques in cases where no market information is available (e.g. contingent valuation, choice modelling)

Figure 7. Overview of the sort of estimation that may be required to cover environmental impacts of R&D. Source: Centre for International Economics.

- the 'ecosystems services' approach to understanding the links between the environment and the economy (or human values more generally).

The economic approach

The economic approach to environmental valuation has emerged over the past 40 years or so and received a significant boost with the focus on sustainable development following the publication of the 'Brundtland report'[1] in 1987 (see WCED 1987). Pearce et al. (1989) also give some of the history of the approach, while Bennett (2011a) covers more recent technical developments.[2]

Environmental economics has been concerned particularly with the economic incentives and institutions that allow or prevent environmental valuations from emerging in various human interactions and therefore being accounted for in decision-making.

For this reason, much of this stream of research has focused on *non-market valuation*. In a sense, the focus of the economic approach has been on identifying potential values that people hold around environmental outcomes, and using and developing a variety of techniques to discover those values.

Ecosystem services

Over roughly the same period, a parallel stream of thinking known as ecosystem services has emerged (see, for example, Costanza et al. (1997)). Initially, this stream was not as concerned with the analytics of valuation (as economists might view things) but in providing an understanding of the ways in which ecosystem structures, processes and functions combine to generate services for other elements of the ecosystem and for humans.

The ecosystem services stream of literature initially had weaker valuation foundations, but recent work has helped reconcile the ecosystem services approach with the traditional economic approach to environmental analysis (see, for example, Bateman et al. (2011) and Johnston and Russell (2011) for a discussion of these issues).

1 So called because the commission that produced it was chaired by Gro Harlem Brundtland, the then Prime Minister of Norway.

2 Pearce (2006) and Pearce et al. (2002) review a range of environmental valuations in developed and developing studies.

The two are complements

A core proposition of this report is that, properly understood, these two approaches are essentially complementary; each adds something that was missing from the other, to provide an overall view that is both descriptively useful and analytically sound.

The economic approach to valuation has solid welfare–theoretic foundations, anchored in an understanding of incentives and in the central role of economic surplus (WTP) as a valuation framework. It is therefore essential for use in cost–benefit analysis. It has been less strong, however, in providing a comprehensive description of the many roles of ecosystems in generating values for humans.

The ecosystem services approach provides extremely useful descriptive lists of ecosystem structures and processes, and the ways in which these may combine to provide value to humans. The approach has pointed out the many complex ways that the economy is grounded in ecosystems. However (particularly in initial applications), the ecosystem services approach was considerably weaker in valuation foundations and, in some early applications, failed elementary theoretical tests that economists would like to apply (by implicitly allowing double counting, for example, or by using valuation techniques that were not grounded in surplus methods). But, as noted above, recent research has shown how the ecosystem services approach can be useful, given appropriate understanding of its underlying economic foundations.

3 Total economic value and non-market valuation

Not all economic value appears in markets

One of the standard approaches to understanding value, commonly used within environmental and resource economics, is to divide total economic value (TEV) into a number of different components, as illustrated in Figure 8.

These different values can apply to a variety of goods and services that are either inputs to, or outputs from, farming and other systems. They apply, of course, to many ecosystem outcomes.

- Direct use values are concerned with immediate or in situ use (either consumptive or non-consumptive) of goods and services (including ecosystem services).
- Indirect use values are concerned, for example, with use of ecosystem services through indirect means, not necessarily in situ.
- Options values are concerned with values that arise because of the potential to use resources in the future rather than now, or because of the potential information that may be contained in those resources (medicinal use of plants, for example).
- Non-use values include existence values and bequest values—valuation not concerned with direct use in any way, but with the existence per se of the resource, or the ability to pass the resource to future generations.

These values can be increased or reduced through policy choices or through R&D, in exactly the same way that use values may be influenced through policy or through R&D. Evaluation of R&D therefore requires evaluation of its impacts on the different sources of value.

One of the core insights of the TEV categorisation is that many types of value are not explicitly traded within markets and so the estimation of such values requires a range of alternative economic techniques.

Table 2 illustrates a broad mapping between the types of values and the expression of those values in markets or otherwise.

Overview of valuation techniques

Where values cannot be derived directly from market exchanges, the estimation of economic value involves looking at a surrogate market (as in revealed preference techniques) or creating a market (as in stated preference techniques). Table 3 broadly summarises the valuation techniques commonly used for environmental values.[3]

Why avoided cost is not necessarily a surplus measure

It is common within some valuations of environmental outcomes to consider 'avoided cost' as a measure of value. Before adopting this measure, it is important to be very clear of what it is designed to measure. Figure 9 illustrates one notion of avoided cost. This represents a variety of cases, but it could be, for example, an environmental benefit leading to a reduction in water treatment costs. This is a productivity improvement in

3 Non-market valuation, particularly using stated preference techniques, is a rapidly expanding area of economic research. The research by Johnston et al. (2011, 2012) indicates the level of care and attention needed in undertaking stated preference studies.

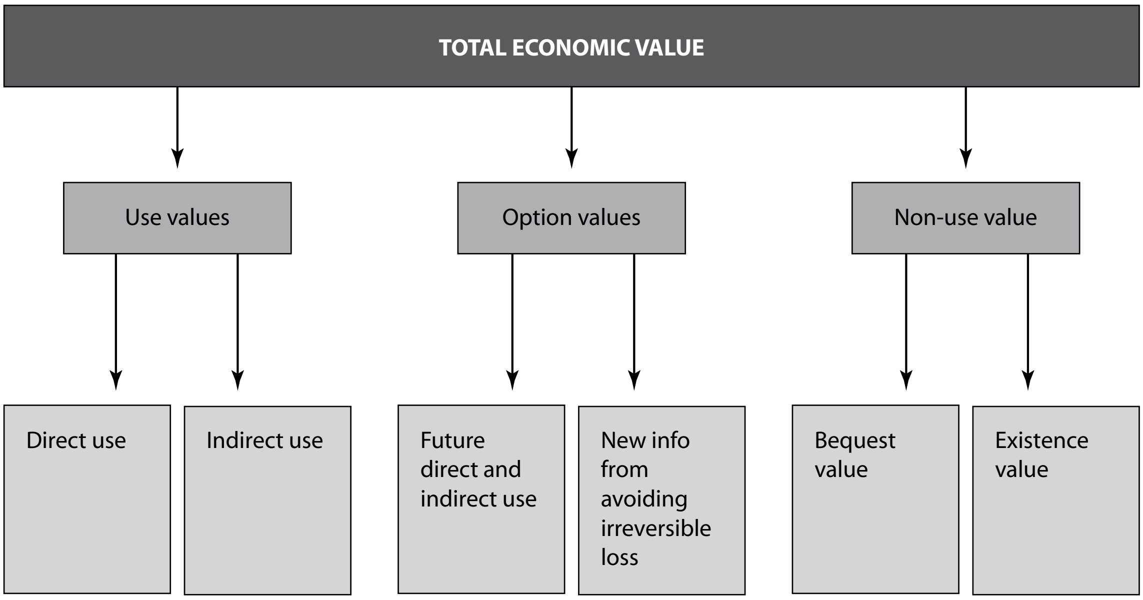


Figure 8. Total economic value and its components. Source: Centre for International Economics.

Table 2. Types of economic values

Expression of value	Direct use	Indirect use	Options	Bequest	Existence
Direct market values (inputs or outputs)					
Undistorted market	■	■			
Distorted market	■	■			
Secondary market values					
Undistorted market		■			
Distorted market		■			
Values implied from indirect market					
Observed transactions/models		■	■	■	
No market values			■	■	■

Source: Centre for International Economics

the supply of water services, represented as a downward shift in the supply curve from S to S_1, and the value of the improvement is measured by the typical surplus area ($abcd = 1/2\ z(Q_1+Q_2)$) shown in the figure. The avoided cost measure is equal to $fP1ce = zQ1$. As such, the avoided cost measure will be an overestimate of the welfare gain in the majority of cases. In fact it is equal to the surplus measure only when the demand cure (D) is perfectly inelastic.

More generally, avoided cost, or avoided damage, or avoided mortality will not necessarily equal the willingness to avoid the cost, damage or mortality. In some cases, however, avoided costs may provide the only available values. In these cases, care should be taken to identify the likely effects of using avoided cost rather than WTP estimates.

Table 3. Valuation techniques for non-marketed environmental outcomes

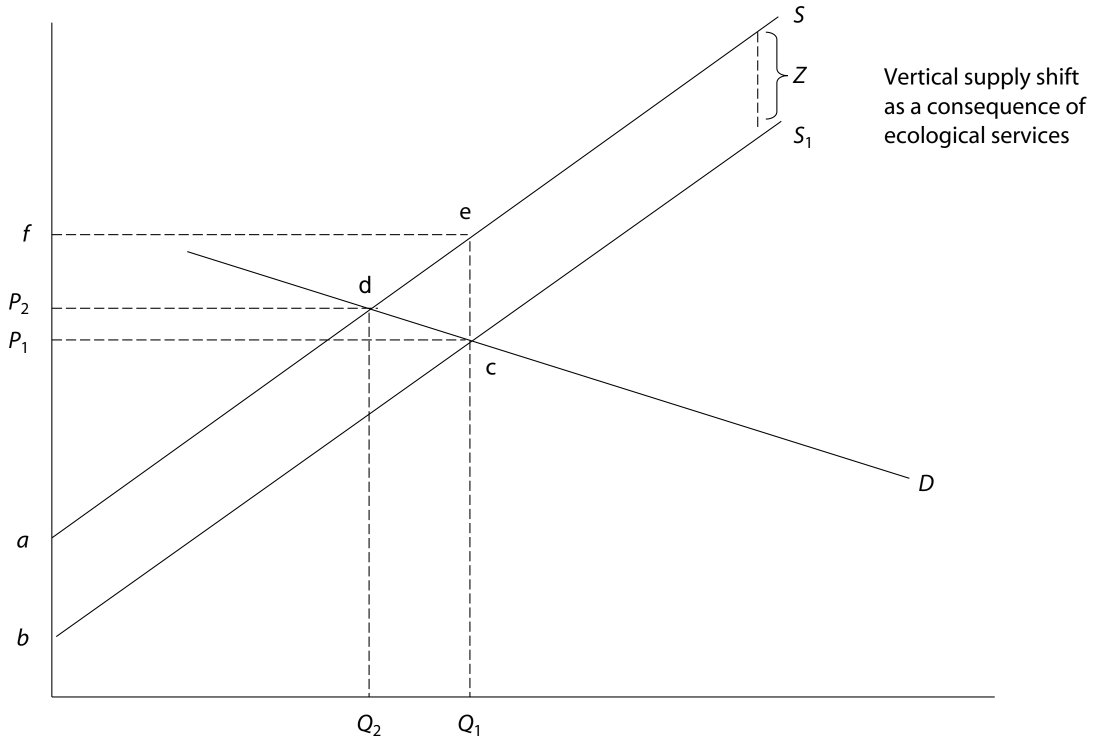
Category of technique and context	**Name**	**Description**
Revealed preference methods These approaches are used where information on market transactions is available and where non-marketed environmental characteristics (or ecosystem services) are implicit in the marketed transactions. Values from the non-marketed ecosystem services are inferred through careful analysis of variations within a large set of market transactions. These techniques are concerned with 'use values' for environmental services.	Travel cost	A technique used to value sites that people incur costs in order to visit. Visits are made for a variety of reasons, but sites of interest are those that have environmental significance. Preference for visitation is inferred from the travel costs incurred: using statistical methods relating visits to distance (and cost), consumer surplus per visit can be estimated.
	Hedonic pricing	This technique is used to estimate value of non-marketed characteristics by using detailed data on market transactions where non-marketed characteristics are implicit in the transactions, can be measured and vary across transactions. It is most often applied to real estate transactions where the overall price of the real estate is a function of many embodied characteristics (including, for example, proximity to areas of environmental significance). This technique is extremely data-intensive.
	Production function	A technique used to estimate values of non-marketed environmental inputs into production processes (which in turn generate a marketed product). Involves statistical estimation of the relationship between inputs and outputs for a farming system in the region of interest. Can be used to determine value of ecosystem services (see discussion elsewhere in this report).
Stated preference methods These techniques involve direct questioning of beneficiaries of environmental services. Questionnaires typically confront respondents with a variety of alternatives and are designed to ascertain choices under these virtual alternatives. These techniques cover non-use values in addition to use or passive use values.	Contingent valuation	These survey methods typically involve a binary choice between different alternatives for environmental outcomes. Although the choice is binary, the alternative outcomes may have a complex set of elements within them. This technique is very flexible and has had wide application in developed countries.
	Choice modelling	Respondents are asked, in effect, to choose between different outcomes where the outcomes are described by a number of attributes. Choices are not binary (as in contingent valuation) so values (willingness to pay) for individual environmental characteristics can be obtained.
	Contingent behaviour	Closely related to choice modelling, this technique seeks to assess respondents reactions to potential future changes in factors such as the price of environmental services. The focus is not on a monetary response ('how much are you willing to pay for …?') but on a behavioural response ('what will you do in the face of …?').

Source: See, for example, Bennett (2011a, b)

Valuing carbon

As noted earlier, an environmental value that is being identified with increasing frequency relates to carbon: either increased sequestration of carbon in biological systems or the avoided emissions of carbon dioxide (and other greenhouse gases) in agricultural systems.

There are several options for valuing these changes in carbon, and care should be taken in thinking through which is most appropriate in a given circumstance. Figure 10 illustrates two broad options for valuing carbon related to R&D.



Surplus gains = $abcd = \frac{1}{2} z (Q_2 + Q_1)$

Cost increase avoided = $fP_1ce = zQ_1$

Surplus = cost avoided only if demand is totally inelastic (that is, if $Q_1 = Q_2$)

Otherwise cost avoided will be an overestimate

Figure 9. Avoided cost and economic surplus

Direct: optimal climate control

The economic value of reducing carbon emissions is equal to the WTP for carbon control, which is, in principle, related to the loss in income avoided as a result of limiting climate change, net of the cost of abatement. Thus, if future climate change is expected to cost $100 (in terms of an appropriate welfare measure), then abatement that eliminates future climate change will have a gross benefit of $100. If the abatement itself cost $50, then the net benefit of the abatement would be $50.

Under this sort of framework, there is a balance between avoiding the future costs of climate change and incurring abatement costs. If all costs and benefits are being considered appropriately, then there would be little sense in incurring abatement costs greater than the cost of climate change.

There are studies that have attempted to estimate the costs and benefits of abatement and climate change in this way (see, for example, Nordhaus and Boyer (2000) and Nordhaus (2010)). These studies can be used to impute a value for each tonne of carbon abated.

In addition, a number of studies have attempted to estimate the marginal damage of each tonne of carbon emitted (using both economic and climate models). This work is summarised by Tol (2010, 2012).

Indirect: cost of hitting a target

The second way of getting to a value for carbon is an indirect approach that estimates the cost of achieving a particular abatement target (whether or not that target is optimal in any sense). Thus, for example, economic model simulations of the cost of the Copenhagen targets can be used to estimate a cost per tonne of carbon abated. (see, for example, Commonwealth of Australia (2011)).

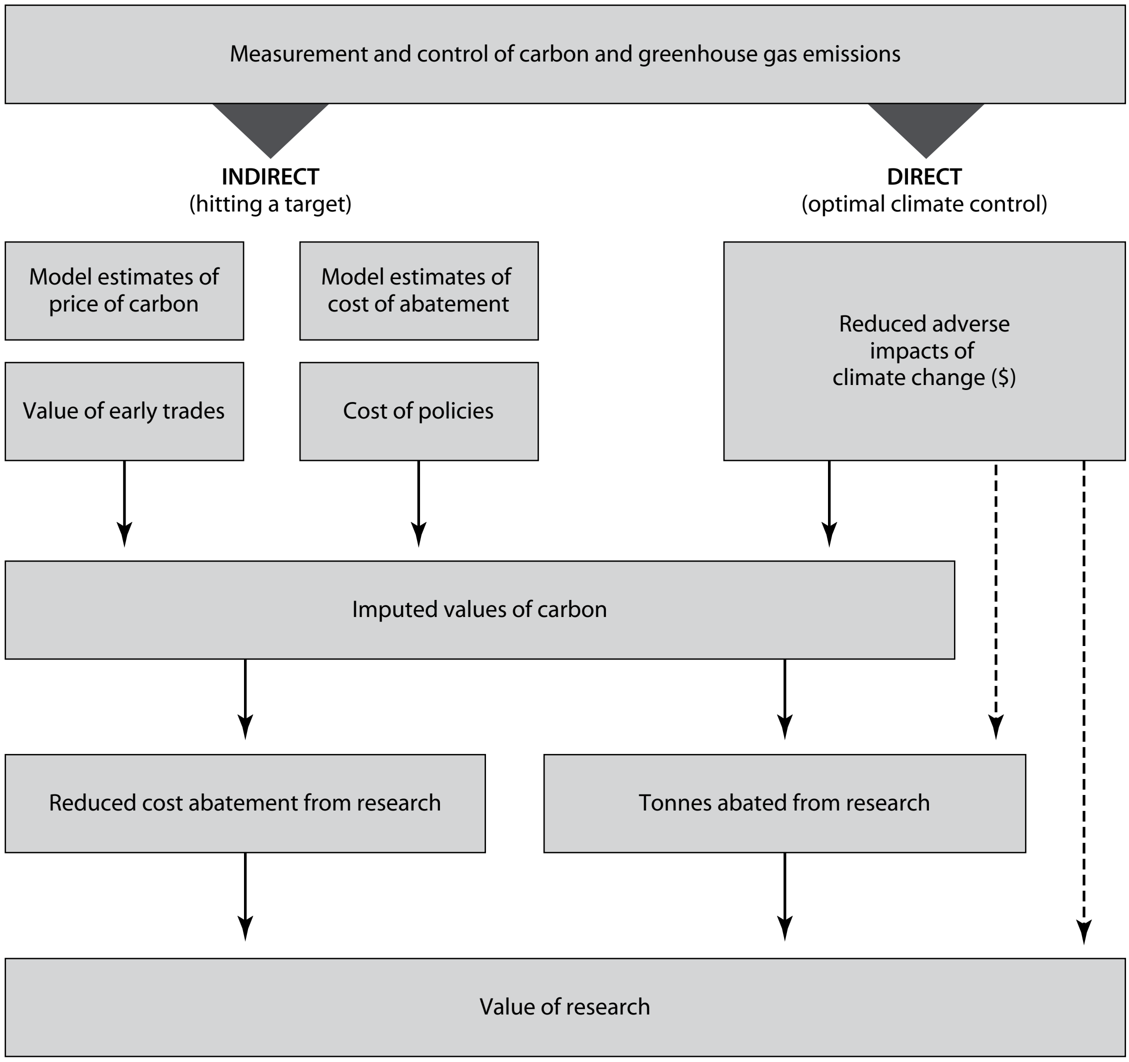


Figure 10. Valuing carbon in relation to R&D. Source: Centre for International Economics.

In addition to model-based estimates of abatement costs, it is also possible to value carbon by observing carbon trades within well-established carbon markets. This value is implicitly determined by the target imposed within the particular market. (The value of carbon trades in a number of markets is summarised at <www.pointcarbon.com>.)

Benefit transfer

The various valuation techniques set out in Table 3 draw on considerable data and specialist analytical techniques. Individual studies are likely to be expensive and time consuming. In developing countries, underlying data may simply be unavailable.

The cost of deriving estimates of environmental values means that a very common approach is to apply 'benefit transfer'; that is, use values generated in another context to apply to the particular context under consideration. Environmental values are transferred from one application to another.

As Figure 11 illustrates, there are several layers of benefit transfer, ranging from the simple adoption of a per-person value from other study, to more sophisticated meta-analysis of information pooled from many studies. The core issue with benefit transfer is the extent to which differences between situations

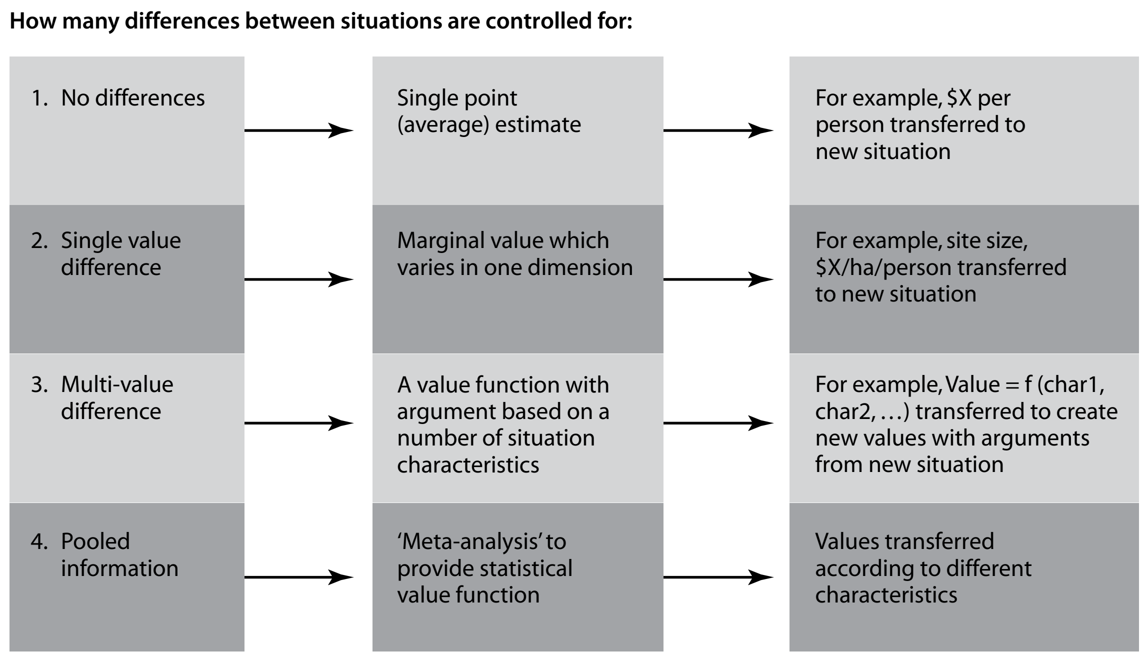


Figure 11. Levels of benefit transfer. Source: Centre for International Economics.

can be measured and therefore taken account of in the transfer process.

One of the major challenges in using benefit transfer as part of any analysis is that there are no generally accepted rules and guidelines as to what constitutes best practice. Although it is widely agreed that meta-analysis provides the most reliable approach to benefit transfer, considerable uncertainty about acceptable practice remains (see, for example, Johnston and Rosenberger (2010)).

4 Ecosystem services

Overview of ecosystem services

Ecosystem services are the contributions of the natural world ('natural capital' or 'natural resources' or 'the environment') that are used (directly or indirectly) to generate goods (or services) that people value.[4]

An ecosystem can be thought of as series of underlying ecological and biophysical structures and processes which together produce *functions* that then generate a range of *ecosystem services* that are (potentially) of *value* to humans (Figure 12). These values may arise through use or non-use reasons, and may require (particularly in the case of direct uses) the combination with other economic inputs to generate the ultimately valued goods and services.

Figure 12 illustrates that there are several steps in moving from the underlying ecological and biophysical structures to the ultimate sources of human value and wellbeing. As will be noted further below, delineating all of these steps is worthwhile as it helps pin down where the sources of scientific uncertainty may arise.

The different categories of ecosystem services set out in Figure 12 are considered in more detail below.

[4] A variety of definitions of ecosystem services can be found (see, for example, TEEB (2010) and Costanza et al. (1997)). These are all essentially equivalent to the core definition used here, although it is worth noting that this discussion draws more on Bateman et al. (2011) who focus strongly on incorporating ecosystem services within an economic framework.

Ecosystem functions and processes

The relationship between ecosystem functions and underlying biological, chemical, physical and ecological process is illustrated in Table 4.

Basic underlying ecological and biophysical process such as photosynthesis, plant nutrient uptake, soil dynamics, nitrogen fixation and so on all contribute to ecosystem functions that include primary production (plant growth), decomposition, nutrient cycling, water cycles and soil formation.

The ecosystem functions (driven from underlying processes) reflect the potential for the ecosystem to deliver services that can then be combined to generate values for humans.

Biodiversity and ecosystem services

Some of the links between biodiversity and ecosystem services are summarised in Table 5. Genetic variability, for example, has the potential to provide a (provisioning) ecosystem service of medicinal products. In this case, of course, ultimate production of the products requires additional human inputs and so cannot be attributed to the ecosystem services (or the biodiversity) alone.

Taxonomy of ecosystem services

Table 6 summarises one taxonomy of ecosystem services. This is derived from the United Nations Environment Programme–hosted 'The Economics of Ecosystems and Biodiversity' (TEEB) project report (TEEB 2010) which, in turn, built on a number of previous taxonomies, including those of Costanza et al. (1997) and the Millennium Ecosystem Assessment (2005).

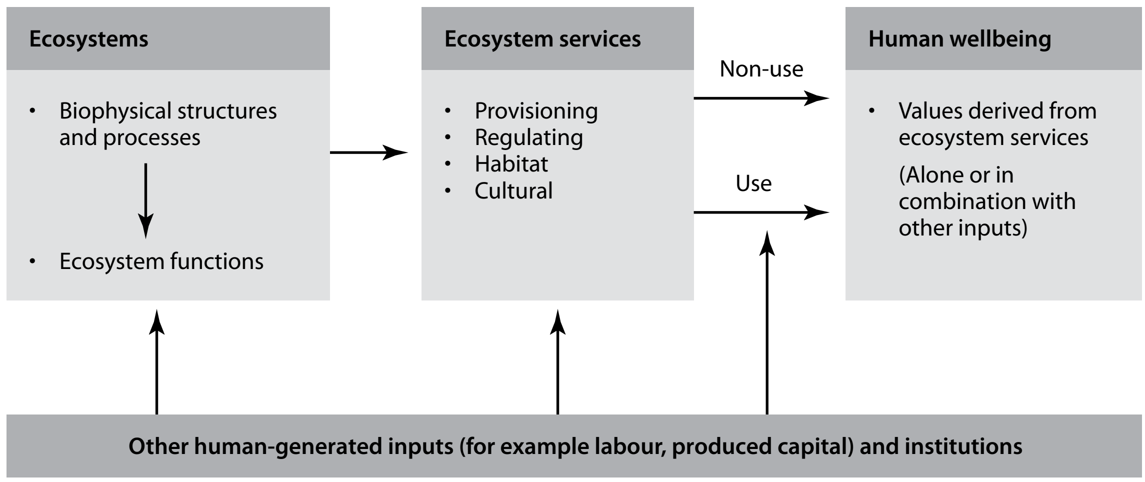


Figure 12. The path from ecosystem processes to human values. Source: based on discussion in TEEB (2010) and Bateman et al. (2011).

Table 6 identifies 22 ecosystem services, divided into four broad categories:

- provisioning services, which include the production of food, water, raw materials and so on
- regulating services, which include air quality regulation, climate regulation, modification of extreme events, soil erosion prevention and so on

Table 4. The relationship between ecosystem functions and processes

Ecosystem function	Processes
Primary production	• Photosynthesis • Plant nutrient uptake
Decomposition	• Microbial respiration • Soil and sediment food-web dynamics
Nitrogen cycling	• Nitrification • Denitrification • Nitrogen fixation
Hydrologic cycle	• Plant transpiration • Root activity
Soil formation	• Mineral weathering • Soil bioturbation • Vegetation succession
Biological control	• Predator–prey interactions

Source: TEEB (2010, table 2.1a).

- habitat services, which include maintenance of habitats for a variety of species
- cultural and amenity services, including opportunities for recreation and tourism, inspiration and so on.

Key aspects of the ecosystem services approach

When considering the analytical application of the ecosystem services approach, four key points need to be taken into account.

Focus is on value to humans

First, the focus is on ultimate goods or services that people value: as in the broader economic approach, it is the values of people that are of interest. This is consistent with the surplus-based or WTP approach to R&D evaluation.

The value of ecosystem services may require combination with other inputs

Second, ecosystem services may generate values directly (through, for example, provision of use or non-use values) or may require combination with other (human-generated) inputs to provide ultimate value to people. This point is very often misunderstood in simple

Table 5. Examples of relationships between biodiversity and ecosystem services

Component of biodiversity	Example of ecosystem service
Genetic variability	• Medicinal products
Population sizes and biomass	• Food from crops and animals
Species assemblages, communities and structures	• Habitat provision and recreation
Interactions between organisms and their abiotic environment	• Water purification
Interactions between and among individuals and species	• Pollination and biological control

Source: TEEB (2010, table 2.1b),

Table 6. A taxonomy of ecosystem services

	Main service types
Provisioning services	
1	Food (for example, fish, game, fruit)
2	Water (for example, for drinking, irrigation, cooling)
3	Raw materials (for example, fibre, timber, fuelwood, fodder, fertiliser)
4	Genetic resources (for example, for crop improvement and medicinal purposes)
5	Medicinal resources (for example, biochemical products, models and test organisms)
6	Ornamental resources (for example, artisanal work, decorative plants, pet animals, fashion)
Regulating services	
7	Air quality regulation (for example, capturing (fine) dust, chemicals etc.)
8	Climate regulation (including C-sequestration, influence of vegetation on rainfall etc.)
9	Moderation of extreme events (for example, storm protection and flood prevention)
10	Regulation of water flows (for example, natural drainage, irrigation and drought prevention)
11	Waste treatment (especially water purification)
12	Erosion prevention
13	Maintenance of soil fertility (including soil formation) and nutrient cycling
14	Pollination
15	Biological control (for example, seed dispersal, pest and disease control)
Habitat services	
16	Maintenance of life cycles of migratory species (including nursery service)
17	Maintenance of genetic diversity (especially through gene-pool protection)
Cultural and amenity services	
18	Aesthetic information
19	Opportunities for recreation and tourism
20	Inspiration for culture, art and design
21	Spiritual experience
22	Information for cognitive development

Source: TEEB (2010, table 1.2).

applications of the ecosystems services approach. For example, fishing (or fish caught) is not an ecosystem service from the perspective of the fisherperson. Rather, the value from fishing comes from the combination of time, fishing gear and other inputs along with a combination of biophysical outcomes (ecosystem services), which may include fish in the water. The value of the ecosystem service is its marginal contribution to the overall fishing enterprise, not the value of the whole fishing enterprise itself. Thus, for example, the value of commodities produced using ecosystem services (such as frozen fish) is not the same as the value of the ecosystem service, as the former value includes the human inputs. If $q = q(m,n)$ is a production function for some good, and m is a vector of human inputs and n is a vector of natural inputs (including ecosystem services), then the increment in q as a consequence of an increment in n (dq/dn) depends on the nature of the production function but, in principle, has a range of potential outcomes.

Some ecosystem services are final and some are intermediate

Third, some ecosystem services will be intermediate in the sense that they are not directly used or valued by humans, but are inputs to other ecosystem services that are. Final ecosystem services are those that directly enhance the welfare of at least one human beneficiary. Intermediate services are those that benefit humans only through their effects on other final services. For example, imagine that nutrient removal (such as in a wetland) leads to increased water clarity in a nearby lake; if water clarity is valued by adjacent households, then nutrient removal is not a final ecosystem service, rather water clarity is (see Johnston and Russell 2011).

This point was also taken up by the UK National Ecosystem Assessment, which used the final ecosystem services listed in Table 7.

Understanding underlying ecology

Fourth, the underlying ecology and biophysical responses behind ecosystem services may be very complicated. Limitations to valuation may be driven by limitations in understanding the underlying science. This implies that a primary focus of any research on the ecosystem impacts of agricultural R&D needs to focus substantively on the underlying biophysical responses. Only if these are correctly characterised will the subsequent valuation be relevant. For example, R&D may lead to an increase in water available in river systems, which may lead to an increase in fish populations and therefore a range of values for humans. The magnitude of the biophysical response from water flows to fish numbers is a crucial variable that must be understood before the valuation of the outcome can take place.

Identifying final ecosystem services and avoiding double counting

The risk of double counting in the valuation of ecosystem services has been a major research concern within this field in recent years.[5] Research by Johnston and Russell (2011) proposed a series of tests to examine whether a particular ecosystem service is in fact a final service that can be appropriately valued. These tests are summarised in Figures 13 and 14.

Essentially, these tests involve:

- ensuring that the ecosystem service actually generates value to some user
- separating the value of the ecosystem service from the value of anthropogenic inputs to production
- making sure that the ecosystem service can be valued of itself (while holding other services constant)
- aggregating only those services that satisfy these tests.

The use of the ecosystem services concept for R&D evaluation

R&D evaluation requires a particular use of the ecosystem services concept. The objective is not to value total ecosystem services. Rather, it is to value the *increment* in ecosystem services that results as a consequence of the complex chain of actions that come about through the adoption of new knowledge, techniques or capacity generated through agricultural R&D.

5 See, for example, Boyd and Banzhaf (2007).

Table 7. Final ecosystem services and corresponding goods: examples from the UK National Ecosystem Assessment

Final ecosystem service[a]	Principal related goods
Production of crops, plants, livestock, fish etc. (wild and domesticated)[b]	Food, fibre, energy, genetic resources, industrial inputs, fertiliser, avoidance of climate stress, recreation and tourism, physical and mental health, ecological knowledge etc.
Production of trees, standing vegetation and peat[b]	Timber, avoidance of climate stress, energy, noise regulation, recreation and tourism etc.
Production of wild species diversity including microbes[b,c]	Natural medicine, disease and pest control, genetic resources, wild food, bio-prospecting, recreation and tourism, physical health, ecological knowledge etc.
Production of water quantity[b,c]	Potable water, industrial use of water, flood protection, energy, recreation and tourism, physical health, ecological knowledge etc.
Regulation of the climate[c]	Avoidance of climate stress, physical and mental health, ecological knowledge etc.
Regulation of hazards; related vegetation and other habitats[c]	Coastal protection, erosion protection, flood protection, avoidance of climate stress, physical and mental health, ecological knowledge etc.
Breakdown and detoxification of waste[c]	Pollution control, waste removal, waste degradation, physical and mental health, ecological knowledge etc.
Purification processes[c]	Clean air, clean water, clean soils, physical health, ecological knowledge etc.
Generation and maintenance of meaningful places; socially valued landscapes and waterscapes[d]	Recreation and tourism, physical and mental health, ecological knowledge etc.

Source: Bateman et al. (2011).

a As noted previously, it may be necessary in some circumstances to combine other inputs (for example, manufactured capital) with final ecosystem services in the production of goods.

b 'Provisioning' services.

c 'Regulating' services.

d Cultural services. 'Supporting' services relate to primary ecological services.

Figure 15 identifies seven points in the broad chain of linkages from ecosystems to human wellbeing at which agricultural R&D may have an impact. Most of these (1, 3, 4 and 6) relate to the effects of adoption of R&D leading to changes in production techniques, while three of them (2, 5 and 7) relate to increases in information or changes in policy regimes.

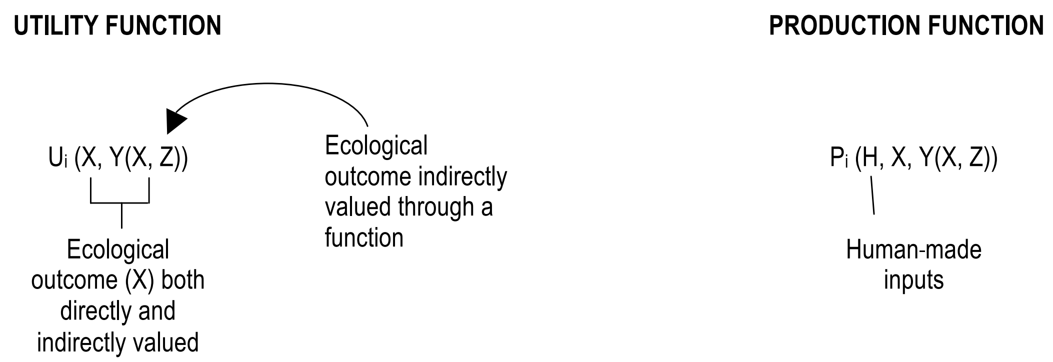
Table 8 examines these potential impacts in more detail, while Table 9 relates them to a more 'traditional' listing of the effects of agricultural R&D on NRM outcomes.

Several key points emerge from Tables 8 and 9:

- where in the chain examination starts is likely to be determined on a case-by-case basis
- later impacts are usually related to impacts farther back in the chain
- there may be large knowledge gaps in many of these impact areas—broadly speaking, the underlying 'production function' may not be as well known as necessary to understand full impacts
- there is considerable scope for R&D to lead to improvements in the knowledge base—both in the relationship between ecosystems and ecosystem services but also the valuation of these.

Linking benefits back to the original point in the process of generating ecosystem services makes the biophysical linkages very clear.

In moving from 1 to 2 to 3, there may be a great deal of scientific uncertainty.



***h* = {X, Y, Z} is a set of biophysical outcomes that may serve as ecosystem services if they satisfy four tests:**

Test 1: ‘It is valuable?’

Is the beneficiary willing to pay for an increase in ‘h’ rather than go without? Is:

$$\frac{dU}{dh} > 0 \quad \text{OR} \quad \frac{dP}{dh} > 0$$

Test 2: Is *h* the output of an ecological system prior to any combination with human labour, capital or technology? An output that combines biophysical outcomes with other factors of production is not an ecosystem service.

Test 3: Is the beneficiary willing to pay for increases in *h* assuming that all other ecosystem outputs are held constant? For example:

$$\frac{dU}{dX} > 0 \text{ for Y fixed and Z fixed} \quad \text{AND} \quad \frac{dP}{dX} > 0 \text{ for Y fixed and Z fixed}$$

BUT

$$\frac{dU}{dZ} = 0 \text{ Y fixed and Z fixed} \quad \text{AND} \quad \frac{dP}{dZ} = 0 \text{ for Y fixed and Z fixed}$$

SO

Z is not a final ecosystem service

Test 4: Are the ecosystem services to be counted and aggregated across beneficiaries all final services?

Figure 13. A structure for identifying ecosystem service value. Data source: Centre for International Economics, based on discussion in Johnston and Russell (2011).

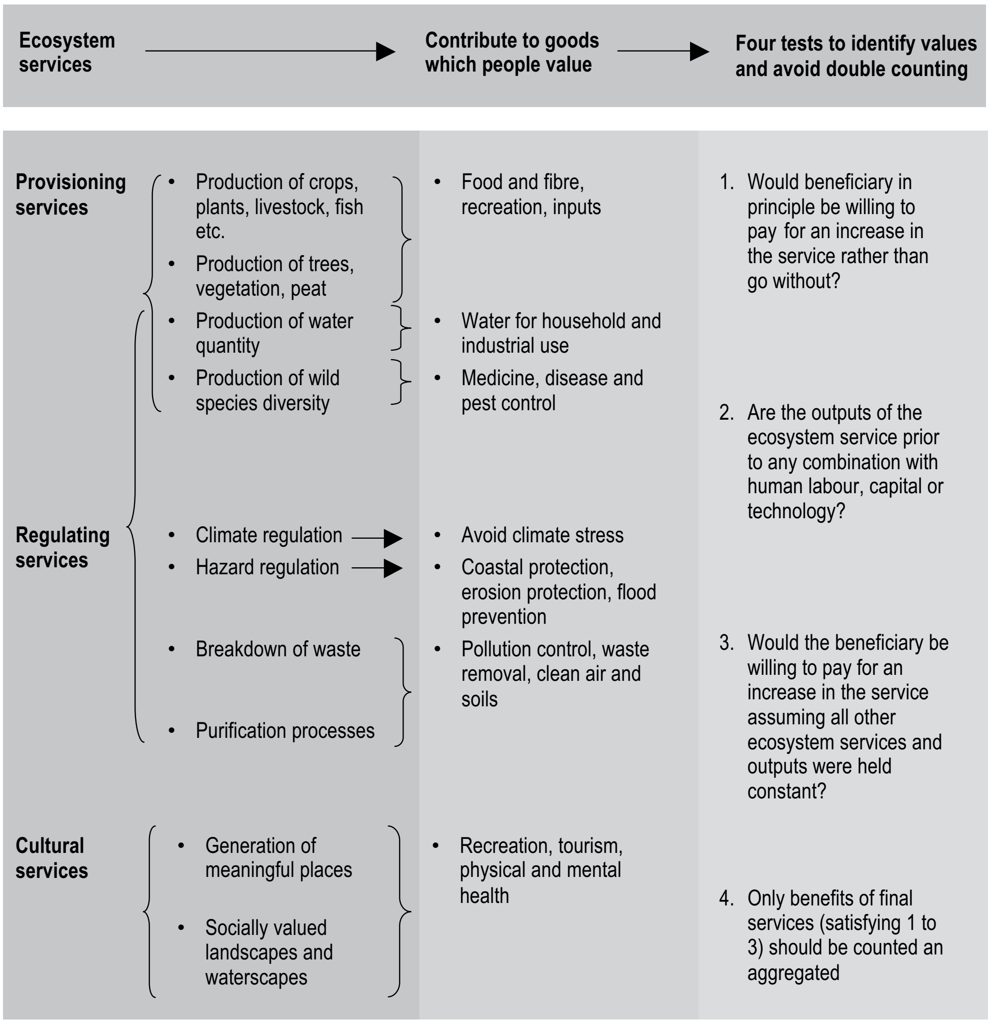


Figure 14. Testing which ecosystem services to use. Source: Centre for International Economics.

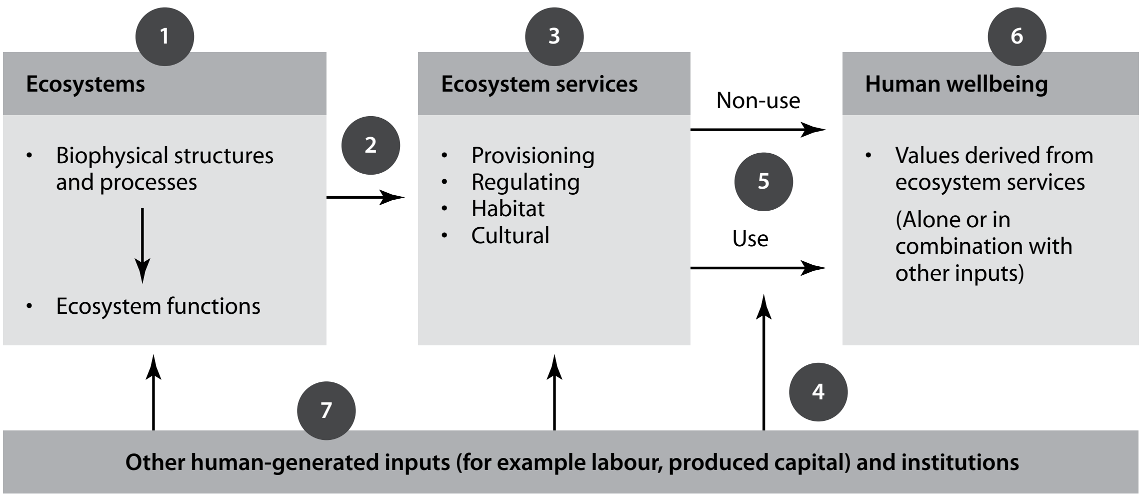


Figure 15. How R&D may impact ecosystem services. Source: Centre for International Economics.

Table 8. Pathways for R&D to impact ecosystem services

	Output related	Input related	Knowledge or policy
Impact 1. Impact of changes induced by R&D on underlying ecosystems themselves	Decrease in emissions of various kinds (smoke, chemicals, processing effluent) may directly affect the functioning of ecosystems.	Reduced withdrawal of resources from ecosystems (water, for example) will affect ecosystem function.	
Impact 2. Change in knowledge about the relationship between underlying ecology and potential ecosystem services			The relationship between ecosystems and potential ecosystem services is complex. R&D may improve basic scientific understanding of these relationships.
Impact 3. Change in the 'volume' or 'quality' of ecosystem services	Increase in the volume of the ecosystem service (such as increased carbon sequestration) may result from production changes related to R&D.		
Impact 4. Improved productivity in the combination of capital and other inputs with ecosystem services	Increased production efficiency in the use of ecosystem services may result in releasing environmental resources for other uses.		
Impact 5. Increased understanding of the relationship between ecosystem services and human wellbeing			The link between ecosystem services and human wellbeing is an issue of ongoing scientific exploration.
Impact 6. Direct increases in human wellbeing	Reduced emissions of various kinds may directly improve human wellbeing (reduced smoke for example).		
Impact 7. Changes in policy broadly relating to ecosystems			Institutional structures and policies have a direct influence on the full ecosystem service chain.

Table 9. Ways of thinking about R&D impacts

NRM research impacts from Zilberman and Waibel (2007)		Corresponding impact within ecosystem service framework (Figure 15)
1.	Improved productivity of natural resources for agricultural purposes (e.g. water conservation, soil and pest management)	**Impact 4**: increased efficiency with which ecosystem services are combined within the agricultural production function. Given knowledge of the relevant production function, this impact is very similar to conventional yield or input efficiency improvements. There may be scientific uncertainty surrounding the nature of the production function, however.
2.	Improved production and natural resource systems for community use (e.g. fisheries, forestry)	**Impact 3**: increased availability of ecosystem services (particularly provisioning services), possibly arising through increased efficiency (**impact 4**) and possibly also underpinned by **impact 1** (where the initial impact of the research may be felt).
3.	Improved human and environmental health via reduced agricultural pollution (mitigating negative effects of agricultural chemicals and other emissions)	**Impact 3 and 6**, but underpinned by **impact 1**. Agricultural pollution may originally impact the underlying biophysical processes and structures **(impact 1)** or may work through the translation of ecosystem function to ecosystems services. Reduced air pollution (from reduced stubble burning, for example) will also directly increase the availability of ecosystem services **(impact 3)** or may enhance the ability of humans to value these ecosystem services **(impact 5).**
4.	Increased availability of environmental amenities (with a particular focus on preserving traditional ways of life and enhancing ecotourism, such as through improved biodiversity and habitat preservation)	**Impact 3**, increased availability of ecosystem services, possibly underpinned by **impact 1**. Potentially also **impact 6,** direct impact on human wellbeing.
5.	Improved policies that govern NRM regimes (policy mechanisms for increased sustainability of natural resource use)	**Impact 7**, the relationship between human institutions and the availability of ecosystem services.

Source: Centre for International Economics' analysis based on Zilberman and Waibel (2007).

An example from forestry research

An analysis by Raitzer (2008) looking at the impact of research on the Indonesian pulp and paper sector by the Center for International Forestry Research provides an interesting example of valuing ecosystem services that change as a result of R&D. Raitzer's results are summarised in Figure 16. Raitzer identifies three broad ecosystem services (water regulation, carbon sequestration and biodiversity) associated with indirect use values and existence values.

For the water regulation and biodiversity outcomes (indirect use value and existence value, respectively), unit values per hectare of forest are derived through benefit transfer from other studies. In this case, the simplest of the benefit-transfer approaches set out in Figure 11 is used.

In the case of carbon sequestration, the estimate for the unit price per tonne of carbon dioxide (CO_2) is based on a conservative estimate of the marginal damage caused by each additional tonne, combined with some indication taken from market prices for carbon (in this case in the European Union Emissions Trading System).

Interestingly, depending on the scenario used, the value of carbon sequestration was between 66 and 90% of the total environmental values.

Type of value	Indirect use value		Existence value
Detail	Water regulation	Carbon sequestration	Biodiversity
Values adopted	\$30/ha (range \$20–\$40)	37–97 t/ha \$5/t CO_2	\$30–\$50/ha (range \$25–\$75)
Valuation approach	Benefit transfer from other studies	Quantity basal on biophysical studies; Price derived from market transactions and damage estimate	Benefit transfer from other studies

Figure 16. Environmental values from forestry research. Data source: Raitzer (2008, table 4).

5 Broad procedures

Key steps

Using the tools of economic valuation and ecosystems services to apply to the evaluation of agricultural R&D involves essentially three broad steps (Figure 17):

- identifying the project impacts within the space of ecosystem services and within the space of economic values
- estimating the response of the ecosystem services to the changes induced by the R&D
- valuing the estimated changes.

Information collection and analysis

Figure 18 sets out a proposed process for undertaking environmental and NRM impact analysis in more detail. It divides the analysis into seven broad steps and implicitly assumes that these are undertaken in conjunction with (or subsequent to) a standard impact evaluation.

Step 1 involves detailed analysis of the biophysical impacts of the R&D. That is, it involves:

- the identification process from Figure 17 as well as identifying the research impacts set out in Figure 15
- as is usually the case with impact assessment, these are the marginal or incremental impacts that occur as a consequence of the research
- in this sense, step 1 presupposes the usual process of identifying the difference between the 'with' and 'without' research outcomes and the usual techniques for identifying this in a real-world context apply.

Step 2 is closely related to step 1 and involves identifying the changes in (potential) ecosystem services that result from the R&D. Part of this identification includes identifying the sorts of values likely to be associated with the ecosystem services, including the crucial question as to whether any of the values are likely to be reflected in markets.

This question is further considered in **step 3** which includes examining:

- institutions within the country under consideration
- any environmental payments or specific policies that may reflect preferences for particular outcomes
- markets for related products (as would be used, for example, in hedonic pricing or a production function approach).

Success in step 3 depends very much on the particulars of the country, commodity and production system under examination. Step 3 is crucial, however, in identifying potential sources of information on general attitudes to environmental trade-offs within the country concerned. While not necessarily as robust or targeted as information from special-purpose surveys, these surveys themselves could not be successful without a sound understanding of broad institutional arrangements relating to environmental matters.

If step 3 results in values that can be applied to the estimated change in the ecosystem service, then it may be appropriate to move directly to step 5. Otherwise, **step 4** would be to collect data suitable for benefit transfer–based analysis, applied to the biophysical responses set out in steps 1 and 2.

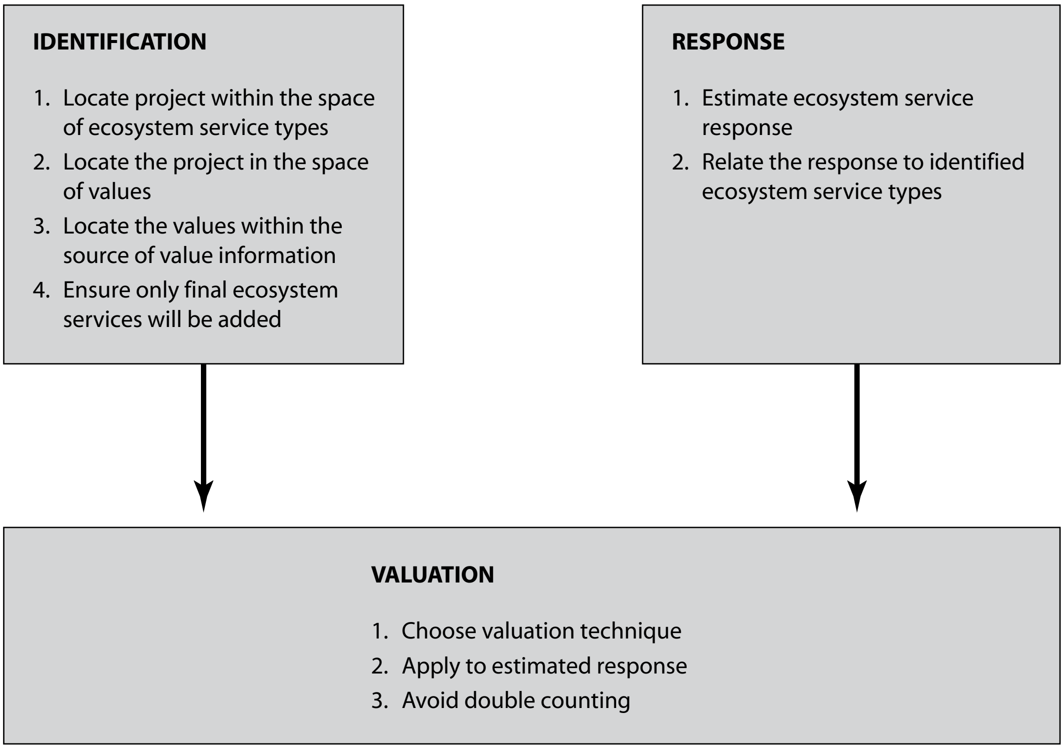


Figure 17. Key steps in environmental evaluation

Because of the uncertainty associated with benefit transfer, this step needs to be treated with a great deal of caution. The initial application of benefit transfer (in **step 5**) should be considered as a means of exploring the potential order of magnitude of effects involved and using these to compare the environmental impacts with the conventional economic impact of the analysis.

Depending on the outcomes from step 5, **step 6** involves deciding on whether to undertake more-detailed analysis of the non-market values of the changes in ecosystem services. There will be a number of factors to take into account here including:

- whether the potential values for the environmental impacts are 'large' relative to the other economic impacts of the research. For example, where the environmental impacts appear large relative to the other economic impacts, or where accounting for the environmental impacts would substantially change the net benefits from the R&D, there is a case for considering more-detailed analysis. Conversely, where the environmental impacts are small (relative to other economic impacts) the case for considering more-detailed analysis is not as strong;
- the resources available to devote to further analysis
- the prospects for success in undertaking further non-market valuation. This is particularly important in some partner countries where primary data collection through survey or other techniques is problematic or expensive.

Finally, **step 7** involves the completion of the cost–benefit analysis. If the conclusion from step 6 was to undertake additional analysis of the non-market values of changes in ecosystem services, then step 7 will involve the completion of the appropriate non-market valuation studies (using, for example, the range of techniques set out in Section 3, and satisfying the conceptual constraints set out in Section 4). Appropriately estimated non-market values can then be placed alongside the market values generated as part of a conventional cost–benefit analysis. If the conclusion from step 6 was to not undertake additional non-market analysis, then step 7 involves proceeding directly to completion of the conventional cost–benefit analysis.

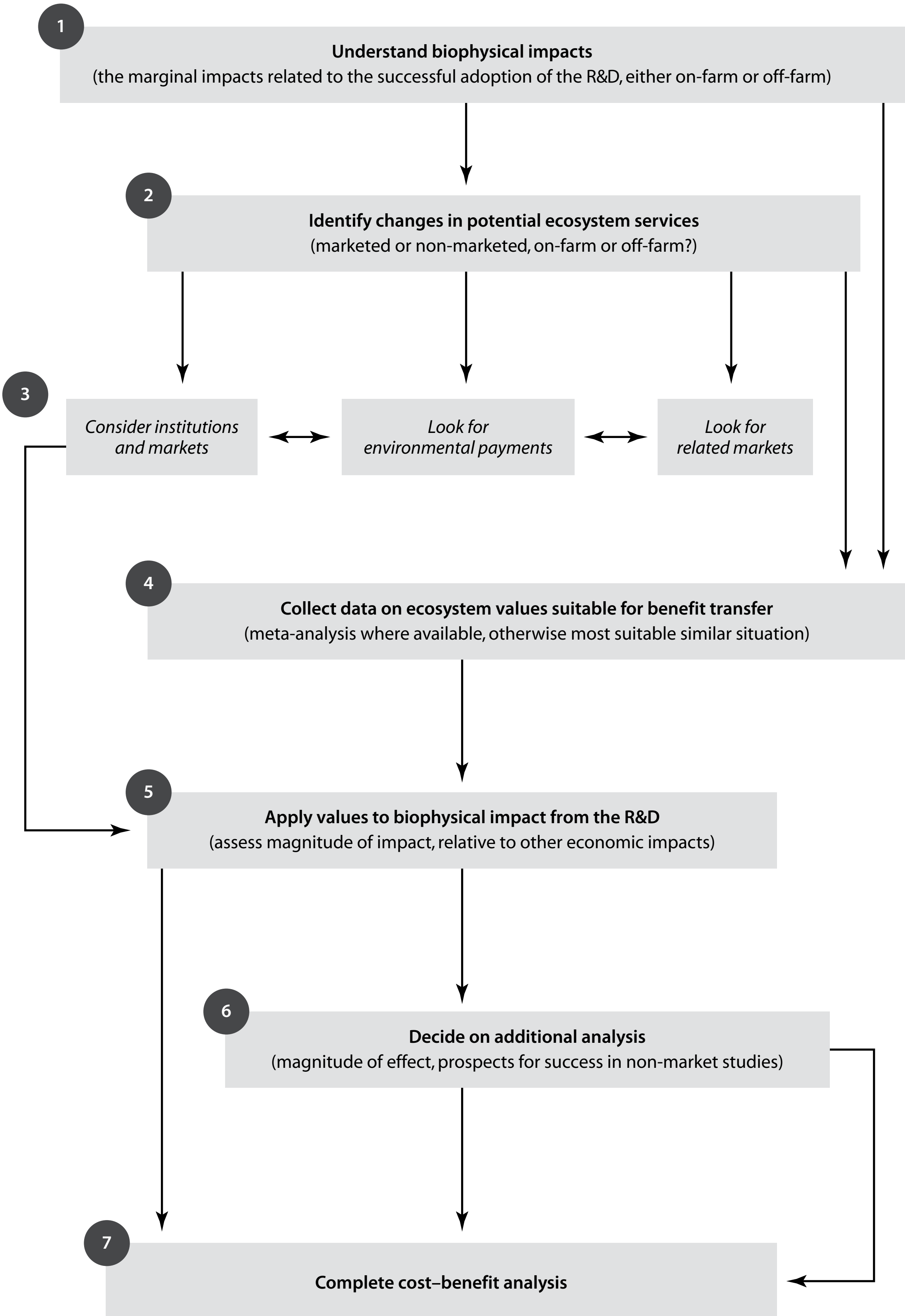


Figure 18. Information collection and analysis: proposed steps. Source: Centre for International Economics.

6 Overview of potential environmental impacts of ACIAR projects

How many projects need environmental evaluation?

An initial scan of all ACIAR projects revealed 356 that could be considered to have NRM or environmental impacts in the sense discussed in this report. These 356 projects then formed the basis of a more detailed consideration of the potential types of environmental impact according to the classification set out in Figure 15 and Table 8.

Examination of the potential outcomes of these 356 projects indicated that only some of them (260, or 73%) would be likely to require specialist environmental valuation. The remaining 96 projects, while containing broad NRM or environmental themes, could be assessed through traditional cost–benefit analysis (CBA).

Figure 19 summarises these findings for each broad program area:

- Agricultural Systems Management
- Fisheries
- Forestry
- Land and Water Resources
- Pacific Crops
- Soil Management and Crop Nutrition.

The projects that can be assessed through traditional CBA usually focus on raising and/or sustaining the productivity of on-farm practices. Such projects usually target individual landholders who receive *private* productivity benefits via NRM improvements. These changes can be valued in traditional markets.

An analysis of NRM and environmental impacts would be required if:

- on-farm changes involve an input or output for which there are traditionally no markets (such as for water)

and/or

- spillover impacts to other landholders or the community can be identified.

Figure 19 shows that forestry projects were almost all deemed as requiring an environmental or NRM impact assessment. This is due to the *potential* for forestry to have significant spillover impacts to the community from ecological services provided by trees, including to matters concerning carbon, salinity and biodiversity. These impacts cannot in part or in their entirety be internalised by landholders.

Research in fisheries (FIS) while having over 80% of projects with potential NRM impacts also has a significant component that may be measured through traditional CBA. The impacts from projects targeting producers of non-communal water resources, such as private fish farms, can often be dealt with through traditional CBA. However, even where such resources are managed exclusively and internalise a productivity benefit similar to a landholder raising the productivity of their crop, some research contains spillover benefits that require NRM impact assessment. For example,

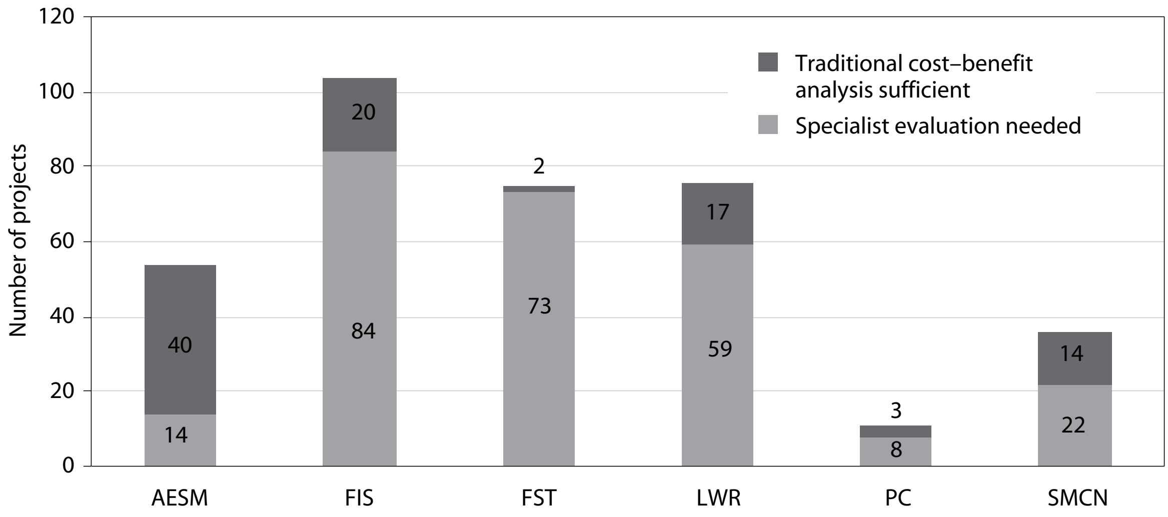


Figure 19. Natural resource management or environmental projects reviewed by program category. Data source: Centre for International Economics, based on ACIAR documents. Note: ASEM, Agricultural Systems Management; FIS, Fisheries; FST, Forestry; LWR, Land and Water Resources; PC, Pacific Crops; SMCN, Soil Management and Crop Nutrition.

many ACIAR projects promote the development of management plans to prevent and control diseases. In addition, some projects may result in NRM impacts when implemented on a wider scale. For example, this may apply to the development of alternative feed sources to arrest the decline in stocks of trash fish—an area that has received considerable attention in the past.

Pathways for R&D to impact ecosystem services

Table 10 summarises the allocation of impacts to the different impact categories. The number of impacts is greater than the number of projects because many projects were identified as potentially having two or more types of impact.

Figure 20 illustrates the composition of projects by classification. Projects often have several aspects to their research and, therefore, many impacts. Below we have grouped the distribution of impacts by the total number of classifications. The composition of impacts by type varies across the program areas, but they can be broadly categorised as follows:

- Impact 4 accounted for between one-third and two-thirds of all impacts identified (improved productivity in the combination of capital and other inputs with ecosystem services).
- Impact 3 consisted of up to one-third of all identified impacts (a change in the 'volume' or 'quality' of ecosystem services).
- Impact 1 comprised up to 13% of all impacts (changes induced by R&D on underlying ecosystems themselves).
- On average, around 20% of impacts (range 13%–42%) were those from changes in policy broadly related to ecosystem services (impact 7). This included changes to institutional structures or capacity to have a direct influence on the full ecosystem service chain.
- Only 3% of impacts were attributable to changing the knowledge about the relationship between underlying ecology and potential ecosystem services (impact 2).
- Very few projects focused on impact 5 (increased understanding of the relationship between ecosystem services and human wellbeing).
- Very few projects concentrated on impact 6 (direct increases in human wellbeing). In reality, however, projects that affect the underlying ecosystems or

Table 10. Classifications of impacts by program area

Impact	ASEM	FIS	FST	LWR	PC	SMCN	Total
1. Impact on underlying ecosystem	0	14	17	12	0	2	45
2. Change in knowledge: ecology to ecosystem service	0	4	5	2	0	0	11
3. Change in volume of ecosystem service	4	25	43	21	0	4	97
4. Improved productivity in use of ecosystem service	6	44	56	36	8	18	168
5. Increased understanding: ecosystem service to wellbeing	0	0	1	0	0	0	1
6. Direct increase in wellbeing	1	1	1	2	0	2	7
7. Changes in policy	8	35	10	22	4	4	83
Total impacts	19	123	133	95	12	30	412
Total number of projects	14	84	73	59	8	22	260
Impacts (number) recorded per project	1.4	1.5	1.8	1.6	1.5	1.4	1.6

Source: Centre for International Economics.

Note: ASEM, Agricultural Systems Management; FIS, Fisheries; FST, Forestry; LWR, Land and Water Resources; PC, Pacific Crops; SMCN, Soil Management and Crop Nutrition.

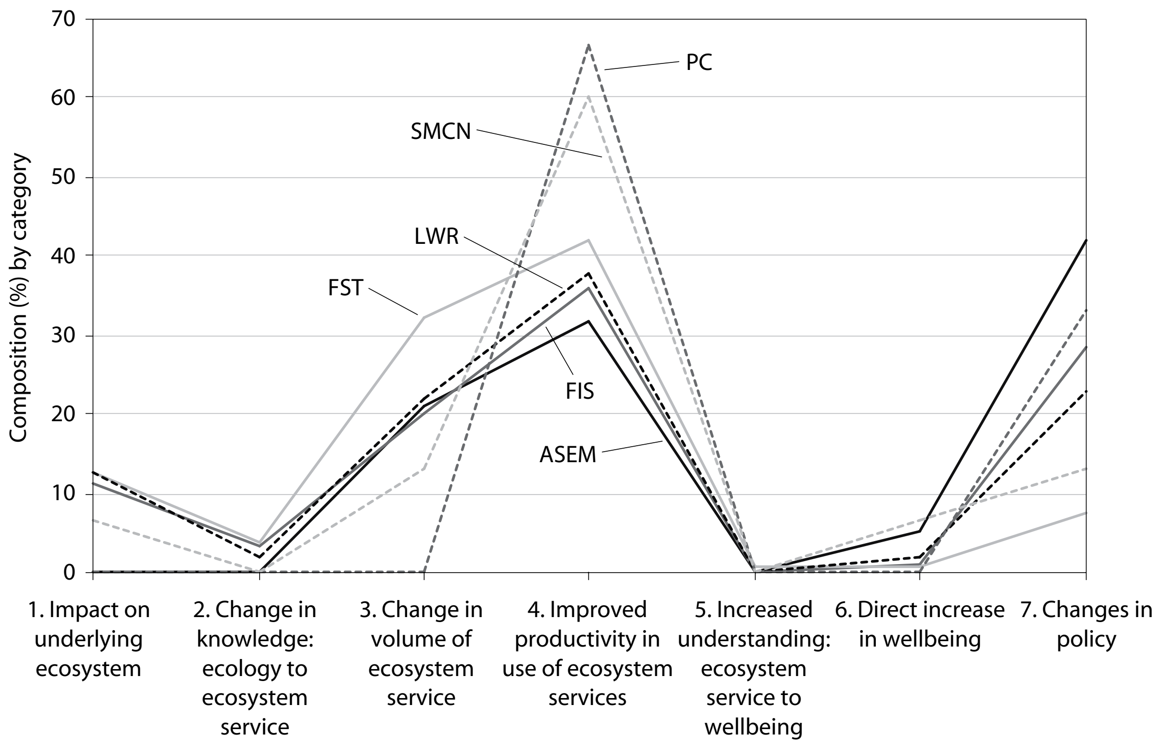


Figure 20. Distribution of impacts by program area. Source: Centre for International Economics. Note: ASEM, Agricultural Systems Management; FIS, Fisheries; FST, Forestry; LWR, Land and Water Resources; PC, Pacific Crops; SMCN, Soil Management and Crop Nutrition.

the quantity, quality or productivity of ecosystem services may increase human wellbeing as an outcome rather than a focus of the research.

Many projects may have links to, or be components of, impact 2. For instance, in forestry, the impacts of many projects fall into 1, 3 and 4 but there may be elements of research undertaken to improve knowledge about the relationship between underlying ecology and potential ecosystem services (impact 2). However, the principal focus of research is usually on the application of existing knowledge or development of new technologies; for instance, to improve productivity in the combination of capital (such as seedlings) and other inputs such as labour, with ecosystem services (impact 4).

Frequency of impact by project

Figure 21 presents this information in a slightly different manner, showing the percentage of *projects* that display each impact, by program area. For example, the results in Figure 21 show that, in almost 60% of cases, ASEM research projects with NRM impacts are expected to have resulted in impact 7: improved policy-making and/ or institutional capacity.

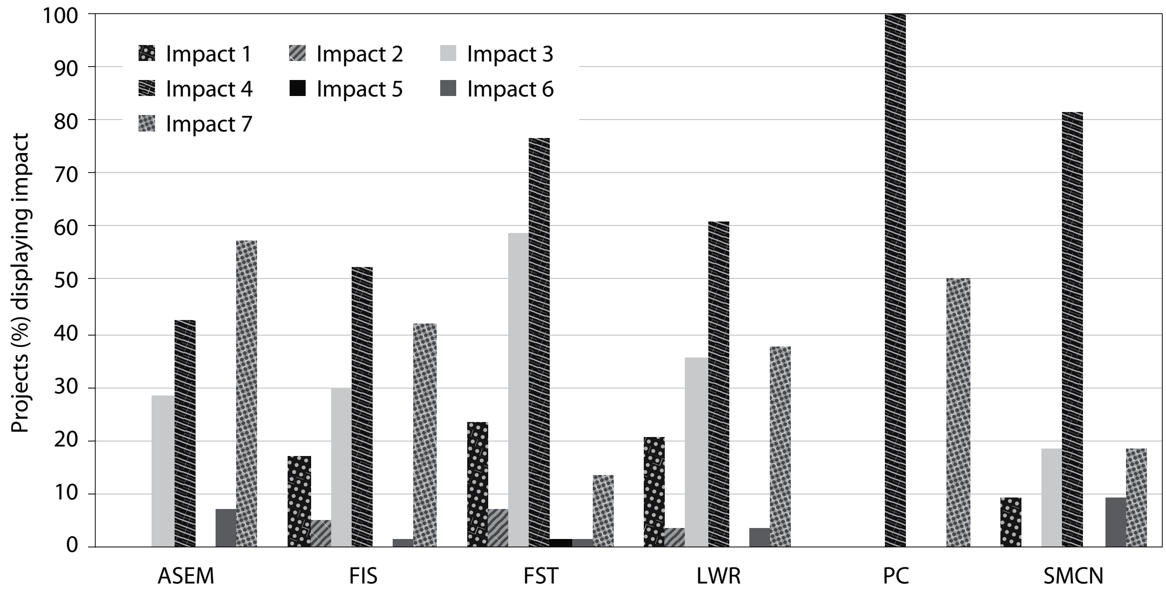


Figure 21. Percentages of projects categorised as displaying impacts 1 to 7. Source: Centre for International Economics. Note: ASEM, Agricultural Systems Management; FIS, Fisheries; FST, Forestry; LWR, Land and Water Resources; PC, Pacific Crops; SMCN, Soil Management and Crop Nutrition.

7 Conclusions

It is clear that environmental and NRM impacts are important for a large number of ACIAR-funded projects spanning a range of program areas.

Evaluating these impacts may require specialist valuation techniques in conjunction with technical understanding of the underlying biophysical relationships that determine ecological outcomes.

It also clear that environmental valuation may involve a degree of complexity beyond that commonly captured in impact assessments. While impact assessments often involve careful analysis of production techniques, the construction of market models and, potentially, the disentanglement of distorted market prices, the incorporation of environmental impacts could involve all of these plus additional overlays of complexity.

The R&D concerned may influence a range of potential ecosystem services that interact in a variety of ways to generate human wellbeing. Importantly, rather than distorted markets prices, the analysis may involve a complete absence of markets, creating particular challenges in deriving the economic welfare effects of R&D outcomes. Techniques to derive values in the absence of specific markets are either data intensive or require extensive primary survey analysis; often expensive in its own right.

It will be important to carefully evaluate the gain from specialist valuation exercises in the context of the overall expected benefits from the project. Where environmental benefits are expected to be a very small share of total project benefits, extensive survey or other analysis may not be warranted (and more limiting procedures such as benefit transfer may be appropriate).

Where environmental benefits are a significant proportion of project benefits, or where there are concerns of that a project might have environmental *costs*, then the case for specialist evaluation becomes much stronger.

In any case, growing interest in environmental impacts (as evidenced by national-level ecosystem service assessments), along with steady developments in analytical techniques, mean that ACIAR is well place to make comprehensive strides towards further understanding of the environmental impacts of the projects it funds.

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IMPACT ASSESSMENT SERIES

No.	Author(s) and year of publication	Title	ACIAR project numbers
1	Centre for International Economics 1998.	Control of Newcastle disease in village chickens	AS1/1983/034, AS1/1987/017 and AS1/1993/222
2	George P.S. 1998.	Increased efficiency of straw utilisation by cattle and buffalo	AS1/1982/003, AS2/1986/001 and AS2/1988/017
3	Centre for International Economics 1998.	Establishment of a protected area in Vanuatu	ANRE/1990/020
4	Watson A.S. 1998.	Raw wool production and marketing in China	ADP/1988/011
5	Collins D.J. and Collins B.A. 1998.	Fruit fly in Malaysia and Thailand 1985–1993	CS2/1983/043 and CS2/1989/019
6	Ryan J.G. 1998.	Pigeonpea improvement	CS1/1982/001 and CS1/1985/067
7	Centre for International Economics 1998.	Reducing fish losses due to epizootic ulcerative syndrome—an ex ante evaluation	FIS/1991/030
8	McKenney D.W. 1998.	Australian tree species selection in China	FST/1984/057 and FST/1988/048
9	ACIL Consulting 1998.	Sulfur test KCL–40 and growth of the Australian canola industry	PN/1983/028 and PN/1988/004
10	AACM International 1998.	Conservation tillage and controlled traffic	LWR2/1992/009
11	Chudleigh P. 1998.	Postharvest R&D concerning tropical fruits	PHT/1983/056 and PHT/1988/044
12	Waterhouse D., Dillon B. and Vincent D. 1999.	Biological control of the banana skipper in Papua New Guinea	CS2/1988/002-C
13	Chudleigh P. 1999.	Breeding and quality analysis of rapeseed	CS1/1984/069 and CS1/1988/039
14	McLeod R., Isvilanonda S. and Wattanutchariya S. 1999.	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008 and PHT/1990/008
15	Chudleigh P. 1999.	Use and management of grain protectants in China and Australia	PHT/1990/035
16	McLeod R. 2001.	Control of footrot in small ruminants of Nepal	AS2/1991/017 and AS2/1996/021
17	Tisdell C. and Wilson C. 2001.	Breeding and feeding pigs in Australia and Vietnam	AS2/1994/023
18	Vincent D. and Quirke D. 2002.	Controlling *Phalaris minor* in the Indian rice–wheat belt	CS1/1996/013
19	Pearce D. 2002.	Measuring the poverty impact of ACIAR projects—a broad framework	
20	Warner R. and Bauer M. 2002.	*Mama Lus Frut* scheme: an assessment of poverty reduction	ASEM/1999/084
21	McLeod R. 2003.	Improved methods in diagnosis, epidemiology, and information management of foot-and-mouth disease in Southeast Asia	AS1/1983/067, AS1/1988/035, AS1/1992/004 and AS1/1994/038
22	Bauer M., Pearce D. and Vincent D. 2003.	Saving a staple crop: impact of biological control of the banana skipper on poverty reduction in Papua New Guinea	CS2/1988/002-C
23	McLeod R. 2003.	Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China	AS1/1984/055, AS2/1990/011 and AS2/1993/001
24	Palis F.G., Sumalde Z.M. and Hossain M. 2004.	Assessment of the rodent control projects in Vietnam funded by ACIAR and AUSAID: adoption and impact	AS1/1998/036

No.	Author(s) and year of publication	Title	ACIAR project numbers
25	Brennan J.P. and Quade K.J. 2004.	Genetics of and breeding for rust resistance in wheat in India and Pakistan	CS1/1983/037 and CS1/1988/014
26	Mullen J.D. 2004.	Impact assessment of ACIAR-funded projects on grain-market reform in China	ADP/1997/021 and ANRE1/1992/028
27	van Bueren M. 2004.	Acacia hybrids in Vietnam	FST/1986/030
28	Harris D. 2004.	Water and nitrogen management in wheat–maize production on the North China Plain	LWR1/1996/164
29	Lindner R. 2004.	Impact assessment of research on the biology and management of coconut crabs on Vanuatu	FIS/1983/081
30	van Bueren M. 2004.	Eucalypt tree improvement in China	FST/1984/057, FST/1987/036, FST/1988/048, FST/1990/044, FST/1994/025, FST/1996/125 and FST/1997/077
31	Pearce D. 2005.	Review of ACIAR's research on agricultural policy	
32	Tingsong Jiang and Pearce D. 2005.	Shelf-life extension of leafy vegetables—evaluating the impacts	PHT/1994/016
33	Vere D. 2005.	Research into conservation tillage for dryland cropping in Australia and China	LWR2/1992/009 and LWR2/1996/143
34	Pearce D. 2005.	Identifying the sex pheromone of the sugarcane borer moth	CS2/1991/680
35	Raitzer D.A. and Lindner R. 2005.	Review of the returns to ACIAR's bilateral R&D investments	
36	Lindner R. 2005.	Impacts of mud crab hatchery technology in Vietnam	FIS/1992/017 and FIS/1999/076
37	McLeod R. 2005.	Management of fruit flies in the Pacific	CS2/1989/020, CS2/1994/003, CS2/1994/115 and CS2/1996/225
38	ACIAR 2006.	Future directions for ACIAR's animal health research	
39	Pearce D., Monck M., Chadwick K. and Corbishley J. 2006.	Benefits to Australia from ACIAR-funded research	AS2/1990/028, AS2/1994/017, AS2/1994/018, AS2/1999/060, CS1/1990/012, CS1/1994/968, FST/1993/016 and PHT/1990/051
40	Corbishley J. and Pearce D. 2006.	Zero tillage for weed control in India: the contribution to poverty alleviation	CS1/1996/013
41	ACIAR 2006.	ACIAR and public funding of R&D. Submission to Productivity Commission study on public support for science and innovation	
42	Pearce D. and Monck M. 2006.	Benefits to Australia of selected CABI products	
43	Harris D.N. 2006.	Water management in public irrigation schemes in Vietnam	LWR1/1998/034 and LWR2/1994/004
44	Gordon J. and Chadwick K. 2007.	Impact assessment of capacity building and training: assessment framework and two case studies	CS1/1982/001, CS1/1985/067, LWR2/1994/004 and LWR2/1998/034
45	Turnbull J.W. 2007.	Development of sustainable forestry plantations in China: a review	
46	Monck M. and Pearce D. 2007.	Mite pests of honey bees in the Asia–Pacific region	AS2/1990/028, AS2/1994/017, AS2/1994/018 and AS2/1999/060

No.	Author(s) and year of publication	Title	ACIAR project numbers
47	Fisher H. and Gordon J. 2007.	Improved Australian tree species for Vietnam	FST/1993/118 and FST/1998/096
48	Longmore C., Gordon J. and Bantilan M.C. 2007.	Assessment of capacity building: overcoming production constraints to sorghum in rainfed environments in India and Australia	CS1/1994/968
49	Fisher H. and Gordon J. 2007.	Minimising impacts of fungal disease of eucalypts in South-East Asia	FST/1994/041
50	Monck M. and Pearce D. 2007.	Improved trade in mangoes from the Philippines, Thailand and Australia	CS1/1990/012 and PHT/1990/051
51	Corbishley J. and Pearce D. 2007.	Growing trees on salt-affected land	FST/1993/016
52	Fisher H. and Gordon J. 2008.	Breeding and feeding pigs in Vietnam: assessment of capacity building and an update on impacts	AS2/1994/023
53	Monck M. and Pearce D. 2008.	The impact of increasing efficiency and productivity of ruminants in India by the use of protected-nutrient technology	AH/1997/115
54	Monck M. and Pearce D. 2008.	Impact of improved management of white grubs in peanut-cropping systems	CS2/1994/050
55	Martin G. 2008.	ACIAR fisheries projects in Indonesia: review and impact assessment	FIS/1997/022, FIS/1997/125, FIS/2000/061, FIS/2001/079, FIS/2002/074, FIS/2002/076, FIS/2005/169 and FIS/2006/144
56	Lindner B. and McLeod P. 2008.	A review and impact assessment of ACIAR's fruit-fly research partnerships—1984 to 2007	CP/1997/079, CP/2001/027, CP/2002/086, CP/2007/002, CP/2007/187, CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1994/115, CS2/1996/225, CS2/1997/101, CS2/1998/005, CS2/2003/036, PHT/1990/051, PHT/1993/87 and PHT/1994/133
57	Montes N.D., Zapata Jr N.R., Alo A.M.P. and Mullen J.D. 2008.	Management of internal parasites in goats in the Philippines	AS1/1997/133
58	Davis J., Gordon J., Pearce D. and Templeton D. 2008.	Guidelines for assessing the impacts of ACIAR's research activities	
59	Chupungco A., Dumayas E. and Mullen J. 2008.	Two-stage grain drying in the Philippines	PHT/1983/008, PHT/1986/008 and PHT/1990/008
60	Centre for International Economics 2009.	ACIAR Database for Impact Assessments (ADIA): an outline of the database structure and a guide to its operation	
61	Fisher H. and Pearce D. 2009.	Salinity reduction in tannery effluents in India and Australia	AS1/2001/005
62	Francisco S.R., Mangabat M.C., Mataia A.B., Acda M.A., Kagaoan C.V., Laguna J.P., Ramos M., Garabiag K.A., Paguia F.L. and Mullen J.D. 2009.	Integrated management of insect pests of stored grain in the Philippines	PHT/1983/009, PHT/1983/011, PHT/1986/009 and PHT/1990/009
63	Harding M., Tingsong Jiang and Pearce D. 2009.	Analysis of ACIAR's returns on investment: appropriateness, efficiency and effectiveness	
64	Mullen J.D. 2010.	Reform of domestic grain markets in China: a reassessment of the contribution of ACIAR-funded economic policy research	ADP/1997/021 and ANRE1/1992/028

No.	Author(s) and year of publication	Title	ACIAR project numbers
65	Martin G. 2010.	ACIAR investment in research on forages in Indonesia	AS2/2000/103, AS2/2000/124, AS2/2001/125, LPS/2004/005, SMAR/2006/061 and SMAR/2006/096
66	Harris D.N. 2010.	Extending low-cost fish farming in Thailand: an ACIAR–World Vision collaborative program	PLIA/2000/165
67	Fisher H. 2010.	The biology, socioeconomics and management of the barramundi fishery in Papua New Guinea's Western Province	FIS/1998/024
68	McClintock A. and Griffith G. 2010.	Benefit–cost meta-analysis of investment in the International Agricultural Research Centres	
69	Pearce D. 2010.	Lessons learned from past ACIAR impact assessments, adoption studies and experience	
70	Harris D.N. 2011.	Extending low-chill fruit in northern Thailand: an ACIAR–World Vision collaborative project	PLIA/2000/165
71	Lindner R. 2011.	The economic impact in Indonesia and Australia from ACIAR's investment in plantation forestry research, 1987–2009	FST/1986/013, FST/1990/043, FST/1993/118, FST/1995/110, FST/1995/124, FST/1996/182, FST/1997/035, FST/1998/096, FST/2000/122, FST/2000/123, FST/2003/048 and FST/2004/058
72	Lindner R. 2011.	Frameworks for assessing policy research and ACIAR's investment in policy-oriented projects in Indonesia	ADP/1994/049, ADP/2000/100, ADP/2000/126, AGB/2000/072, AGB/2004/028, ANRE1/1990/038, ANRE1/1993/023, ANRE1/1993/705, EFS/1983/062 and EFS/1988/022
73	Fisher H. 2011.	Forestry in Papua New Guinea: a review of ACIAR's program	FST/1994/033, FST/1995/123, FST/1998/118, FST/2002/010, FST/2004/050, FST/2004/055, FST/2004/061, FST/2006/048, FST/2006/088, FST/2006/120, FST/2007/078 and FST/2009/012
74	Brennan J.P. and Malabayabas A. 2011.	International Rice Research Institute's contribution to rice varietal yield improvement in South-East Asia	
75	Harris D.N. 2011.	Extending rice crop yield improvements in Lao PDR: an ACIAR–World Vision collaborative project	CIM/1999/048, CS1/1995/100 and PLIA/2000/165
76	Grewal B., Grunfeld H. and Sheehan P. 2011.	The contribution of agricultural growth to poverty reduction	
77	Saunders C., Davis L. and Pearce D. 2012.	Rice–wheat cropping systems in India and Australia and development of the 'Happy Seeder'	LWR/2000/089, LWR/2006/132 and CSE/2006/124
78	Carpenter D. and McGillivray M. 2012	A methodology for assessing the poverty-reducing impacts of Australia's international agricultural research	
79	Dugdale A., Sadleir C., Tennant-Wood R. and Turner M. 2012	Developing and testing a tool for measuring capacity building	
80	Fisher H., Sar L. and Winzenried C. 2012	Oil palm pathways: an analysis of ACIAR's oil palm projects in Papua New Guinea	ASEM/1999/084, ASEM/2002/014, ASEM/2006/127, CP/1996/091, PC/2006/063, PC/2004/064, CP/2007/098

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