Paper submitted to the 18th Annual Conference of the European Association of Environmental and Resource Economists

The environmental benefits of investment in agricultural science and technology: an application of global spatial benefit transfer

Alistair McVittie[1], Salman Hussain[1], Luke Brander[2], Alfred Wagtendonk[2], Peter Verburg[2],
Olivier Vardakoulias[1]

[1] SAC, West Mains Road Edinburgh, EH9 3JG
[2] Institute for Environmental Studies (IVM), VU University Amsterdam
Corresponding author: alistair.mcvittie@sac.ac.uk

Abstract

Food security is a major current and future policy concern. The world population is projected to reach 9 billion by 2050 and continuing growth in economic output and incomes is expected to result in changing food consumption patterns. In particular the wider adoption of 'Western' diets will result in both higher calorie intake and greater meat consumption. Continuing climate change is expected to add further pressures to agricultural production.

This paper presents the results of a global analysis funded by the TEEB study on the environmental benefits of investment in agricultural knowledge, science and technology, specifically in terms of closing the gaps between developing and developed country agricultural productivity. The results show that by easing pressures on land use change on terrestrial biomes (forests and grasslands), and the ecosystem services they provide, investment in agricultural science and technology provides environmental benefits of US$161.3bn per annum in 2050. Between 2000 and 2050 these benefits amount to US$2,964bn in addition to US$6,343bn in carbon benefits and compare to costs of US$5,68bn.

1 Introduction

There is evidence of a widespread loss of ecosystem quality at different scales (local, regional and global), a loss which is on-going and does not appear to be slowing down (Butchart *et al*., 2010). The most recent edition of the United Nations' Global Biodiversity Outlook estimates that 17% of known species are 'endangered' or 'critically endangered' and a further 27% are in a 'vulnerable' or 'near-threatened' condition; further, the 2010 goal of 'significantly reducing the rate of loss' has not been achieved (Convention on Biological Diversity, 2010). The Economics of Ecosystems and Biodiversity (TEEB) is a UNEP-funded project aimed at mainstreaming the valuation and evaluation of ecosystems and biodiversity. It is a response to this conservation agenda, focusing on the lack of the valuation of nature resulting in a failure to take account of the value of ecosystems and biodiversity in decision making (TEEB, 2008). This study contributes to this on-going process.

This paper uses global benefit transfer and cost estimates to evaluate the economic efficiency of investing in agricultural knowledge science and technology (AKST) in order to reduce future pressures on natural biomes for food production to meet the needs of an increasing global population and changing consumption patterns. A necessary condition for economic efficiency is that net benefits should be positive. Testing for economic efficiency requires that the incremental impact of a project or policy is assessed in terms of the benefits to society and the costs of implementation, accounting for when these costs and benefits are borne. We estimate the benefits and costs of investment in AKST: do these outcomes have positive net benefits.

In section 2 we summarise the biophysical data that we use for the assessment of the scenario which we describe in section 3. Section 4 describes the valuation data and benefit transfer process. Results are presented in section 5 and discussed in section 6.

2 Biophysical data

The GLOBIO model

In a complimentary study to our own economic analysis PBL (2010) used the GLOBIO3 model to assess the biodiversity impacts of a number of conservation option scenarios. The GLOBIO3 model is part of a modelling framework developed from existing approaches (IMAGE-NCI[1] and GLOBIO2) to evaluate the 2002 targets set by the Convention on Biological Diversity (CBD) and World Summit on Sustainable Development (WSSD), primarily the, 'significant reduction in the current rate of biodiversity loss at the global, regional, and national level; as a contribution to poverty alleviation; and to the benefit of all life on Earth' (Alkemade *et al.*, 2009). The model uses a number of cause-effect relationships to link environmental drivers to biodiversity impacts. The two primary outputs from GLOBIO are mean species abundance (MSA) and ecosystem extent (PBL, 2010).

MSA is a composite indicator that indexes the abundance of original species remaining in disturbed ecosystem patches relative to the abundance in a pristine, undisturbed state. MSA is calculated for five drivers:

1. land use;
2. nitrogen deposition;
3. infrastructure;
4. fragmentation; and
5. climate change.

These five drivers are assumed to affect the abundance of original species remaining relative to the pristine, undisturbed state, i.e. MSA. The extent to which MSA is affected varies across the five drivers and is derived from a review of relevant literature and expert judgement of their effects. An overall MSA figure is obtained by combining the five drivers through multiplication. For further details and clarification of the assumptions and modelling outputs see PBL (2010).

However, MSA is a value free indicator that weights all species equally regardless of their contribution to ecosystem services. Further the MSA scores are specific to each biome (i.e. pristine desert will have a higher MSA value than degraded tropical forest even if the latter has a higher species abundance). Consequently it is difficult to apply economic valuation to MSA due the equal weighting of species regardless of benefits and the in ability to make trade-offs between biomes (i.e. land use change). Therefore our analysis is limited to the changes in ecosystem extent predicted by the GLOBIO model. Further, only changes in terrestrial biomes (forests and grasslands) are considered.

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[1] Natural Capital Index (NCI) module of the Integrated Model for Assessment of the Global Environment (IMAGE).

Land cover change within the IMAGE model is derived from an extended version of the GTAP agriculture and trade model (PBL, 2010). The outputs from GTAP include sectoral production growth rates, land cover and the degree of intensification. Exogenous trends in crop yields (due to technology, science and knowledge transfer) are adjusted through a process of iteration between IMAGE and GTAP in which the effects of climate change and land conversion are calculated in IMAGE (PBL, 2010).

Model baseline scenario

The baseline for the GLOBIO projections is based on the OECD ‘Environmental Outlook to 2030’ report[2] (OECD, 2008), and runs from a base year of 2000 to 2050. The main characteristics of the OECD baseline are:

- World population grows from 6 to 9 billion
- Fourfold increase in economic output (~ 2.8% per annum)
- Per capita incomes grow particularly in BRIC countries
- Agricultural productivity increases at 1.8% per annum – does not keep pace with population or consumption patterns
- No change in environmental or trade legislation
- Timber demand increases with population and incomes
- Global mean temperature increases to 1.6ºC above pre-industrial level
- No change in protected areas (14%)

Further details with regards the underlying assumptions are provided in PBL (2010).

3 Agricultural productivity

Since the industrial revolution, agricultural productivity has increased more than ten-fold world-wide, primarily as a consequence of the intensification of Western agricultural production. Intensification has also occurred in parts of the developing world, particularly following the green revolution (Evenson and Gollin, 2003). Yet disparities exist globally between regions and there is evidence of the growth rate of agricultural productivity levelling off (van Vuuren *et al.*, 2009). Many propositions have been advanced for explaining this trend: reduced investment in agricultural R&D (Pardey *et al.*, 2006); a general decrease of policy focus on agriculture (Bello, 2010; McIntyre *et al.*, 2009); land degradation and desertification (Bai *et al.*, 2008) as a consequence of poor land management or over-intensification of agricultural practices (FAO, 2008; Vitousek *et al.*, 1997).

The baseline for this scenario (based on Rosegrant *et al.,* 2009; van Vuuren *et al.,* 2009; and FAO, 2008) assumes the current levelling-off of agricultural productivity growth persists. Cumulative productivity growth from 2000 to 2050 is projected to be 25.6% (0.64% p.a.). Specifically, annual productivity growth is assumed to be 1% for cereals, 0.35% for soybeans, roots and tubers, 0.8% for fruits and vegetables, 0.74% for livestock and 0.29% for dairy.

Under the baseline year-on-year increase in yield remains constant, but the rate of growth in food demand is projected to outstrip yield growth as a consequence of population and economic growth; and increased demand for meat - an outcome of changing dietary patterns due to economic growth in developing countries (FAO, 2008). Pressure for conversion of

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[2] http://www.oecd.org/document/20/0,3343,en_2649_34283_39676628_1_1_1_37465,00.html

natural areas (approximately 10%) is projected mostly in the tropical and sub-tropical zones (OECD, 2008).

In the modelled scenario average global agricultural yields are increased by closing the yield gap between developed and developing countries - an upward convergence of agricultural productivity. In developing countries productivity growth is spurred by investment in AKST, increasing productivity by 40% and 20% by 2050 for crop and livestock respectively.

Cost estimates

The costs of the scenario are explicitly based on the study Agriculture at a Crossroads (IAASTD, 2009). This combined partial equilibrium (IMPACT) and computable general equilibrium (CGE) models (GTEM) to analyse alternative scenarios and their impact on agricultural yields to 2050. The study considered five factors as catalysts of growth in yield: (1) investment in education in rural areas, particularly focusing on women; (2) investment in rural roads; (3) irrigation management; (4) access to clean water; and (5) agricultural R&D.

The ‘AKST high 2’ scenario in IAASTD (2009) is used in PBL (2010) and estimates costs at circa US$30 billion per annum. The pertinent question is whether this cost estimate is realistic and defensible, but evidence is limited in this regard. Schmidhuber *et al* (2009) provide an estimate of capital requirements needed for agriculture up to 2050 if developing countries are to meet FAO baseline projections (FAO, 2006). It is not possible to draw a like-for-like comparison between IAASTD (2009) and Schmidhuber *et al* (2009) as the outcomes for which costs are estimated differ. The overall total estimate in the latter study is US$5.2 trillion, a figure considerably higher than the IAASTD estimate.

The IAASTD (2009) figures might under-estimate costs owing to assumptions vis-à-vis policy implementation; there is evidence (e.g. Easterly, 2002; Rist, 2001) that ‘big pushes’ in terms of development aid has often not fulfilled the investment requirements of developing countries.

Notwithstanding the caveats discussed above, we use the cost estimates provided in IAASTD (2009). The figure of US$30 billion per annum is not used as we consider net costs, i.e. additional investment requirements rather than total cumulative investments. We assume that the profile of these investments is flat. As such the figure used for costs is US$14.5 billion per annum. Overall discounted costs from 2000 to 2050 are presented in Table 1.

Table 1 Cumulated costs of closing the yield gap (Billion US$ 2007).

	Discount rate		
	0%	**1%**	**4%**
Cost estimate for option scenario 1	725	568.3	311.5

Source: Based on Rosegrant *et al*. (2009) in IAASTD (2009)

4 Benefits

Benefit database development

The valuation studies used for the benefit transfer were identified from the TEEB valuation database (van der Ploeg *et al.*, 2010)[3]. The TEEB database contains 1,298 individual entries across 14 biomes with temperate and tropical forests accounting for 105 (8%) and 260

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[3] The TEEB database is to be made available on the web but the URL location is not yet available.

(20%) of values respectively. Woodlands studies account for 3% of studies in the database, and grasslands are just under 5% of studies.

We initially reviewed the studies in the TEEB database to determine the suitability of the values for further analysis. Several studies were rejected primarily where values were derived through benefit transfer. Other reasons included: the value being for an entire country rather than site; insufficient information to identify the site size or benefiting population. In some cases values were added, for example where the paper aggregated a number of individual site values or where additional values were stated in the paper.

All values were converted to a common unit: 2007 US$/ha/annum. Values in perpetuity or over a specific time period were converted to present values using discount rates as quoted in the studies (or an appropriate local discount rate). Per-household values were aggregated using relevant local, regional or national household estimates[4] (or rejected if the relevant population could not be identified) and then divided by site area. Finally, per ha values in local currency units were adjusted to 2007 values using appropriate national GDP deflators and then converted to US$ using the relevant purchasing power parity exchange rate[5]. Data for currency conversions and deflations were obtained from the World Development Indicators dataset (World Bank, 2010).

We then added a number of site-specific spatial variables from publically available biophysical and socio-economic datasets. These site-specific variables are used in value function estimation and the subsequent value transfer.

Forest biome database

Fifty eight temperate forest and 103 tropical forest values were selected for inclusion in our analysis. A further 16 values were obtained for the woodlands biome; given this small number these were included with the temperate forest biome for value function development and transfer. Table 2 summarises the ecosystem service categories represented by the values for temperate and tropical forest biomes. There is a high representation of provisioning and regulating services in the tropical forest biome. The main provisioning services considered are non timber forest products (NTFP), particularly food resources, and the provision of raw materials. The range of regulating services includes climate regulation, moderation of extreme events, regulating water flow, waste treatment, erosion prevention and pollination. This wide range of services arises as the tropical forest studies often set out to estimate values for all ESs provided. By contrast, nearly half of the temperate forest biome values relate to cultural services, specifically recreation.

We can speculate that the reason for these differences between studies for the forest biomes is that in temperate regions ‘natural’ forests have been more fully exploited. The studied tropical forest sites are relatively under-exploited and thus more complete information on service provision is needed to balance trade-offs in land use decisions. The other major difference between service coverage between the biomes is that there is a higher proportion of studies (17% versus 4%) relating to supporting services (biodiversity

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[4] Estimates were obtained for household numbers in Denmark, Finland and Australia (Queensland) from national statistical agency online databases.

[5] The reason for converting a reported US$ estimate to local currency using the appropriate PPP exchange rate and then back to 2007 US$ was so as to track changes in the local currency. Those studies that elicited values from foreign visitors were not subject to this conversion.

conservation) in the temperate forest studies. Regulating service values make up a fifth of the temperate forest values. The locations of the study sites for each of the forest and woodland biomes are illustrated in Figure 1.

Table 2 Ecosystem service categories covered by the temperate and tropical forest studies.

Ecosystem service category	Temperate Forest		Woodlands		Tropical Forest	
Provisioning services	8	14%	10	63%	43	42%
Regulating services	11	19%	1	6%	32	31%
Cultural services	28	48%	2	13%	22	21%
Supporting services	10	17%	2	13%	4	4%
Total economic value	1	2%	1	6%	2	2%
Total	58		16		103	

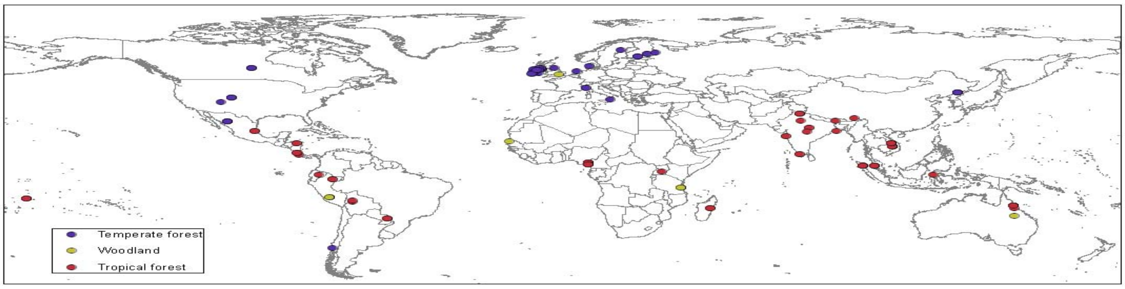

Figure 1 Forest biome site locations and services.

Grassland biome database

Twenty seven grassland valuation studies were collected. Of these, 11 provided both primary value estimates and complete information on all the explanatory variables. From the 11 studies we coded 19 separate value observations, i.e. different study sites or ESs. The locations of study sites included in the database are largely in Northern Europe (Netherlands; United Kingdom; Sweden; Germany), one study from North America (Colorado, US), two from Africa (South Africa; Botswana), and two from Asia (Israel; Philippines). We have no information on the value of ESs from grasslands in South America. Table 3 summarises ES provision across these studies.

Table 3 Ecosystem service categories valued in grassland studies.

Ecosystem service	Number of observations	Percentage
Food provisioning	6	32%
Recreation and amenity	7	37%
Erosion prevention	3	16%
Conservation	3	16%

Biome-level value functions

The aim of benefit function estimation is to produce a model that explains variation in site values in a theoretically and statistically robust manner. Explanatory variables should have some reasonable theoretical justification for both having an effect and the direction of that effect; that effect should also have a reasonable level of statistical significance.

An important decision in function estimation is the choice of functional form to be used. Common throughout the meta-analysis and benefit transfer literature is the use of either log or log-log functions. There are a number of reasons why a log or log-log functional form is attractive (see Brander *et al.*, 2006). Often values follow skewed (non-normal) distributions with a small number of extreme outlying values; a log transformation counteracts this by reducing the effect of extreme values and the resulting data more closely reflect a normal distribution and has a smaller variance. The use of a log-log specification normalises both dependent and independent variables and has the advantage that estimated coefficients can be interpreted as elasticities, i.e. the coefficients represent the percentage change in the dependent variable (value per ha) of a small percentage change in the explanatory variable (Brander *et al.*, 2006).

Explanatory variables should be observable for both study and policy sites. It is common in meta-analyses of valuation studies to include study-specific variables that relate particularly to the methodology that was applied. The effect of different valuation methods or the different value elicitation approaches have been found to be significant explanatory variables; see Bateman and Jones (2003), Lindhjem and Navrud (2008), and Barrio and Loureiro (2010) for examples of meta-analyses of forest valuation studies where this occurs. Although such analyses are of theoretical interest and useful in guiding methodological development, their use for benefit transfer is limited as such variables are unobservable at policy sites.

We use spatially referenced variables derived from publically available data sources,these are applied to the study sites by GIS using each study site's location. Table 4 summarises these spatial variables. GIS was used to transform and integrate the spatial datasets into separate datasets that cover the biomes under investigation. The spatial variables were applied at three different radii from each biome patch: 10km, 20km and 50km. The spatial data selection is based on the following criteria: (1) possible explanatory value for ecosystem value estimates; (2) completeness vis-à-vis global extent; (3) spatial and temporal consistency; and (4) credibility, i.e. well-documented and preferably scientifically referenced data. There are four sequential stages to the GIS integration and analysis work. The first three pertain to the benefit function estimation:

1. Spatial data selection, acquisition, transformation and integration of input data for spatial variables and biome maps
2. Import of study sites into the GIS data base as point locations, based on their estimated geographic coordinates
3. Extraction of spatial variable values to point-based study site locations as input for meta-regression analysis

The fourth step (up-scaling of spatial relationships resulting from the meta-regression analysis between ecosystem values and explanatory spatial variables to a global scale) takes place after the generation of the biome-level value functions.

Table 4 Spatial variables used in benefit function development.

Variable	Description	Comments	Source
Forests	Area (ha) of biome within 10, 20, and 50km	Substitute or complimentary sites	GLC2000 database http://www-gem.jrc.it/glc2000
Grassland			
Mangrove			Mangrove GIS shapefile, Mangroves of Western Central Africa GIS shapefile. UNEP World Conservation Monitoring Centre.
Wetlands			Global lakes and wetlands database GLWD. WWF and Center for Environmental Systems Research, University of Kassel, Germany. http://www.worldwildlife.org/science/data/item1877.html
Rivers and lakes			
Coral reef			Coral reef 1km data in ESRI Grid format and Shapefile
Gross cell product	Measure of gross value added (PPP US$ 2005)	Proxy for ability (willingness) to pay	Global Economic Activity G-Econ 3.3. http://gecon.sites.yale.edu/data-and-documentation-g-econ-project
Population	Population density (2000 persons/km^2) (10, 20, 50km)	Population likely to benefit /exert pressure on ecosystem services	Socio-Economic Data Center (SEDAC) Columbia University. http://sedac.ciesin.columbia.edu/gpw/global.jsp
Urban area	Area (ha) of urban land use (10, 20, 50km)		Institute for Environmental Studies, University of Wisconsin-Madison http://www.sage.wisc.edu/people/schneider/research/data.html
Roads	Length (km) of roads (10, 20, 50km)	Measure of accessibility and/or fragmentation of site	FAO - UN SDRN http://www.fao.org:80/geonetwork?uuid=c208a1e0-88fd-11da-a88f-000d939bc5d8
Net primary product (NPP)	Net primary product of actual vegetation (gC/m^2/yr) (10, 20, 50km)	Proxy measure of ecosystem services provision	Institut für Soziale Ökologie IFF - Fakultät für interdisziplinäre Forschung und Fortbildung der Alpen-Adria-Universität Klagenfurt Wien, Österreich. http://www.uni-klu.ac.at/socec/inhalt/1191.htm
Human appropriate of NPP	Human appropriation of NPP (gC/m^2/yr) (10, 20, 50km)	Proxy measure of human exploitation of ecosystem services	
Accessibility index	Index of accessibility based on distance in travel time to urban centres	Measure of accessibility and use of ecosystem services	Aurelien Letourneau, Wageningen University aurelien.letourneau@wur.nl

Temperate forests and woodlands value function

The value function outlined in Table 5 was found to have the best performance in terms of variable significance and goodness-of-fit. A number of other explanatory variables that could be observed across both the primary valuation sites and transfer sites were tested and found not to be significant; these included location variables such as regional dummies. The estimated coefficients have the expected signs. The negative sign on the log of site area indicates that values per ha decline as the size of the site increases, i.e. diminishing margin values. The log of gross cell product within 50km is positive indicated that site values increase with income. The positive sign on the log of urban area within 50km of the sites suggests that values for natural areas increases with the local urban population; this would be expected given the predominance of recreational values in the temperate forest studies. The final independent variable included is the log of human appropriation of net primary product (NPP) within 50km of the study sites, a proxy for land cover intensity. The negative sign on the estimated coefficient could be interpreted to mean that more intensive land use surrounding forest sites reduces their value.

The coefficients are significant at the widely accepted 5 and 10% levels, although LN_GCP50 (Gross Cell Product) is marginally insignificant under these criteria. However, removal of such variables can serve to reduce the significance of those remaining or the overall model performance. The adjusted R^2 indicates that this model accounts for 34.8% of the observed variation in log per ha values.

Table 5 Temperate forest and woodland value function.

Variable name	Variable definition	Beta	Std. Error	Sig.
Constant		28.627	6.124	0.000
LN_AREA	Natural log of the study site area	-0.420	0.076	0.000
LN_GCP50	Natural log of Gross Cell Product within 50km radius	0.247	0.150	0.104
LN_URB50	Natural log of urban area within 50km radius of study site	0.245	0.143	0.092
LN_HAN50	Natural log of human appropriation of NPP within 50km radius of study site	-1.610	0.417	0.000
N		69		
Adjusted R^2		0.348		

Tropical forests value function

Table 6 outlines the estimated value function. There are four independent variables in common with the temperate forest function; these have the same signs and interpretation. The additional variables include the area of forest within 50km of the site and the length of roads within 50km; both of these have negative signs. For the former this can be interpreted as the effect of local substitute sites that can provide a similar range of ESs. The negative sign on the log of roads within 50km variable suggests that this variable might be a proxy for the degree of forest exploitation. The adjusted R^2 figure indicates that 39.2% of observed variation in values is explained by the model. With the exception of the LN_HAN50 and LN_RDS50 variables each variable is significant at either the 5% or 10% level.

Table 6 Tropical forest value function.

Variable name	Variable definition	Beta	Std. Error	Sig.
Constant		12.960	4.071	0.002
LN_AREA	Natural log of the study site area	-0.230	0.070	0.001
LN_GCP50	Natural log of Gross Cell Product within 50km radius	0.402	0.173	0.022
LN_URB50	Natural log of urban area within 50km radius of study site	0.424	0.121	0.001
LN_HAN50	Natural log of human appropriation of NPP within 50km radius of study site	-0.394	0.292	0.181
LN_FOR50	Natural log of area of forest within 50km radius of study site	-0.336	0.202	0.100
LN_RDS50	Natural log of length of roads within 50km radius of study site	-0.204	0.131	0.124
N		102		
Adjusted R^2		0.392		

Grasslands value function

Given the very limited sample size of grassland ecosystem service values, the number of explanatory variables that can be included in the value function is low. The explanatory variables included in the value function are GDP per capita; the area of grassland within a 50km radius of the study site; the length of road within a 50 km radius of the study site; and the accessibility index. The value function is presented in Table 7.

The estimated coefficients on the explanatory variables all have the expected signs but are mostly not statistically significant[6]. Only the estimated effect of accessibility is statistically significant at the 10% level, although the GDP per capita variable is significant at the 12% level. The positive coefficient on the income variable (GDP per capita) indicates that grassland ecosystem services have higher values in countries with higher incomes, i.e., grassland ecosystem services are a normal good for which demand increases with income. The negative effect of grassland abundance (area of grassland within 50km radius) on value indicates that the availability of substitute grassland areas affects the value of ecosystem services from a specific patch of grassland. The negative effect of roads on grassland values captures the effect of fragmentation on the provision of ESSs from grassland. Grasslands that are more fragmented by roads tend to have lower values. The positive coefficient on the accessibility index indicates that grassland areas that are more accessible tend to have higher values.

The adjusted R^2 of 0.27 indicates that the estimated model only explains 27% of variation in the value of grassland. Although all but one of the explanatory variables included in the model are not statistically significant the signs and magnitudes of effect of the explanatory variable do make theoretical sense. We therefore cautiously use this value function to estimate site specific values for grasslands.

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[6] The presence of insignificant independent variables is of concern; however the estimated model is otherwise theoretically consistent. The lack of significance indicates low precision in the degree to which the coefficients predict the effect of the independent variables on per ha values. We would argue that rejecting the value function for this biome entirely would result in the omission of potentially significant values in our subsequent analysis.

Table 7 Grasslands value function

Variable name	Variable definition	Beta	Std. Error	Sig.
Constant		-2.366	5.094	0.444
GDPPC_LN	Natural log of country level GDP per capita (PPP US$ 2007)	0.856	0.514	0.120
GRA50_LN	Natural log of area of grassland within 50km radius of study site	-0.029	0.142	0.839
RDS50_LN	Natural log of length of roads within 50km radius of study site	-0.225	0.213	0.309
SITES_AI	Accessibility index	2.590	1.322	0.072
N	17			
Adjusted R^2	0.27			

GIS analysis: up-scaling values

The fourth substantive GIS step is the up-scaling of spatial relationships resulting from the meta-regression analysis between ecosystem values and explanatory spatial variables to a global (or regional) scale. The outputs of GLOBIO are changes in the extent of biome extent within regions. The pertinent methodological question is as follows: if a patch changes in extent, what is the value of that change given the local spatial characteristics? There are five sub-steps:

1. Preparation and mapping of seven different non-overlapping biomes represented at patch level.
2. Construction of global datasets with selected variables, covering the spatial extent of all considered biomes.
3. Integration and analysis of GLOBIO modelling data resulting in change factors for all grid-cells concerning land use change, infrastructure change, economic change and water quality change. Spatial transfer to full spatial extent of selected biomes.
4. Combination for each biome of all relevant spatial variables into one raster map.
5. Export to tables of all relevant variables and change factors per biome for statistical processing of value functions (outside GIS environment, using SPSS)

The final stage of the GIS work involves the import and mapping of aggregated table results (value changes) to patch level maps of biomes to present overall results.

5 Results

In this section we present the results of the value transfer exercise and valuation of the investment in AKST option scenario. The value changes are based on the three terrestrial biomes (temperate forests, tropical forests and grasslands) which were modelled in GLOBIO. The results are presented at the level of the 7 regions used by PBL (2010), as illustrated in Figure 2.

Changes in carbon storage

We treat carbon storage as a separate ES as the benefits are truly global in nature and do not rely on an appraisal of local socio-ecological conditions to the same extent as other ES (*c.f.* Barbier *et al.*, 2008). Further, there is a well-established literature on the valuation of changes in carbon fluxes. In our cost benefit analysis we use alternative measures of the value of carbon to provide some sensitivity. These are the Social Cost of Carbon (SCC) estimated by Defra (2007), the POLES and RICE models[7], Table 8 summarises these carbon values out to 2050.

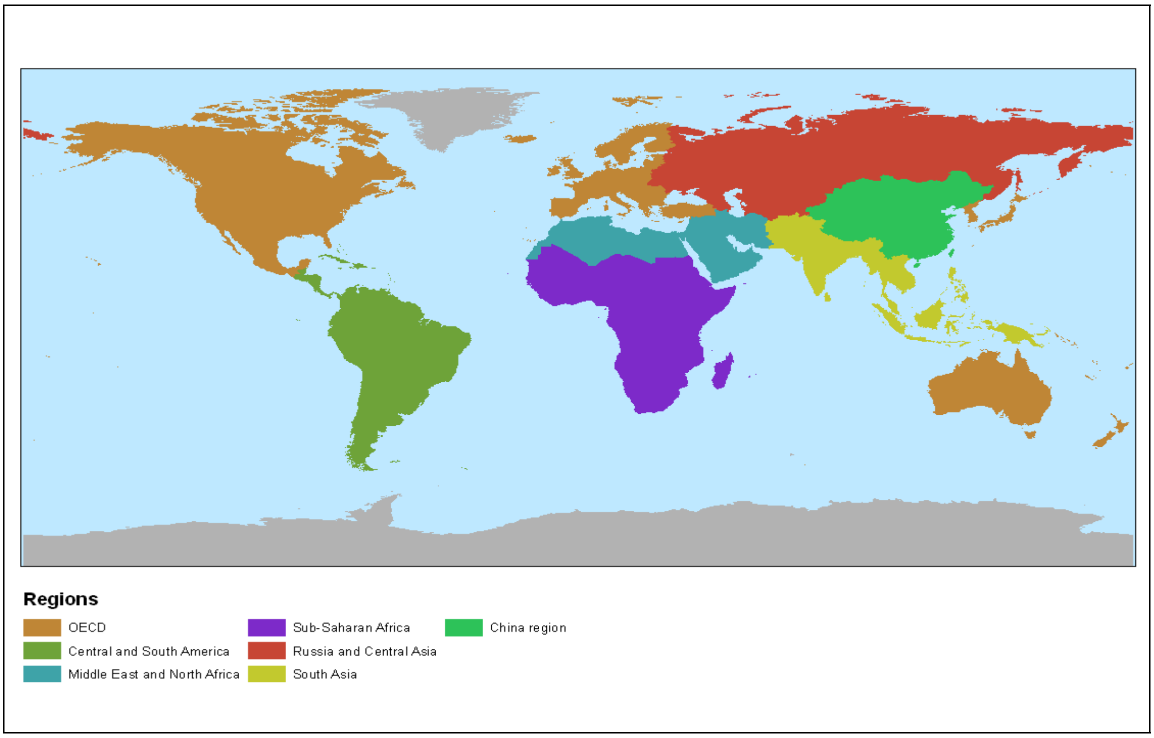

Figure 2 Map of reporting regions

The IMAGE-GLOBIO models consider changes in three main flows: (1) deforestation, (2) re-growth of vegetation, and (3) increased carbon sequestration by existing forests (fertilisation). Policy scenarios can impact upon all three flows. For instance, a reduction in agricultural land reduces deforestation, increases the re-growth of vegetation and affects sequestration by increasing the area of natural forest, but also by reducing atmospheric CO_2 concentrations[8].

The analysis of carbon storage changes that are modelled by the IMAGE-GLOBIO team for the policy scenario at five yearly might be treated as adjunct and preliminary values or co-benefits; the results are presented at an aggregated level (global) in our study. The bio-physical carbon value results (based on SCC) are presented in Table 9.

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[7] For details of the Poles model see: http://webu2.upmf-grenoble.fr/iepe/textes/POLES8p_01.pdf. For a further discussion of the RICE model see: Nordhaus WD and Yang Z (1996) A Regional Dynamic General-Equilibrium Model of Alternative Climate Change Strategies, *American Economic Review* 886: 741-765.

[8] http://www.pbl.nl/en/publications/2006/Integratedmodellingofglobalenvironmentalchange.AnoverviewofIMAGE2.4.html

Table 8 Alternative carbon values for emissions in years out to 2050 (US$2007 per tonne CO_2e)

Year	POLES	SCC	RICE High	RICE Low
2000		29		
2005	0	32	10	5
2010	8	34	13	7
2015	11	38	17	9
2020	37	42	22	10
2025	59	47	28	12
2030	107	53	35	13
2035	182	63	41	14
2040	256	74	48	16
2045	331	93	55	18
2050	406	112	61	21

Table 9 Modelled projections of changes in carbon storage and values relative to the baseline

Year	Carbon storage (bn tonnes CO_2e)	Carbon value (bn US$2007 Defra SCC)
2000	0.00	0.00
2005	-0.57	-17.92
2010	0.04	1.25
2015	1.39	52.94
2020	0.96	40.23
2025	2.49	117.56
2030	2.41	126.38
2035	3.05	192.57
2040	2.85	209.57
2045	3.70	343.97
2050	3.74	420.75
Total (all years)	**90.88**	**6,342.82**

Agricultural Productivity

Figure 3 presents the percentage changes in land cover for each biome under the high AKST scenario relative to the baseline. There are increases in the area of each biome in each region with the exception of small reductions in temperate forest in the 'Middle East and North Africa' and in grasslands in 'Russia and Central Asia', the latter being due to an expansion of arable cropping in Central Asia into previously unsuitable areas (PBL, 2010). Most of these changes are below 10% and so might be described as marginal. The approximately 40% increase in grassland area in 'South Asia' counteracts a 25% decline in that biome under the baseline relative to the 2000 baseyear; the increase is thus a more modest 5% when compared to the 2000 situation.

A value map by region is presented in Figure 4 for the high AKST change in productivity. These results are also presented by region and by biome (Table 10); with the overall aggregated results from 2000 to 2050 at three discount rates in Table 11.

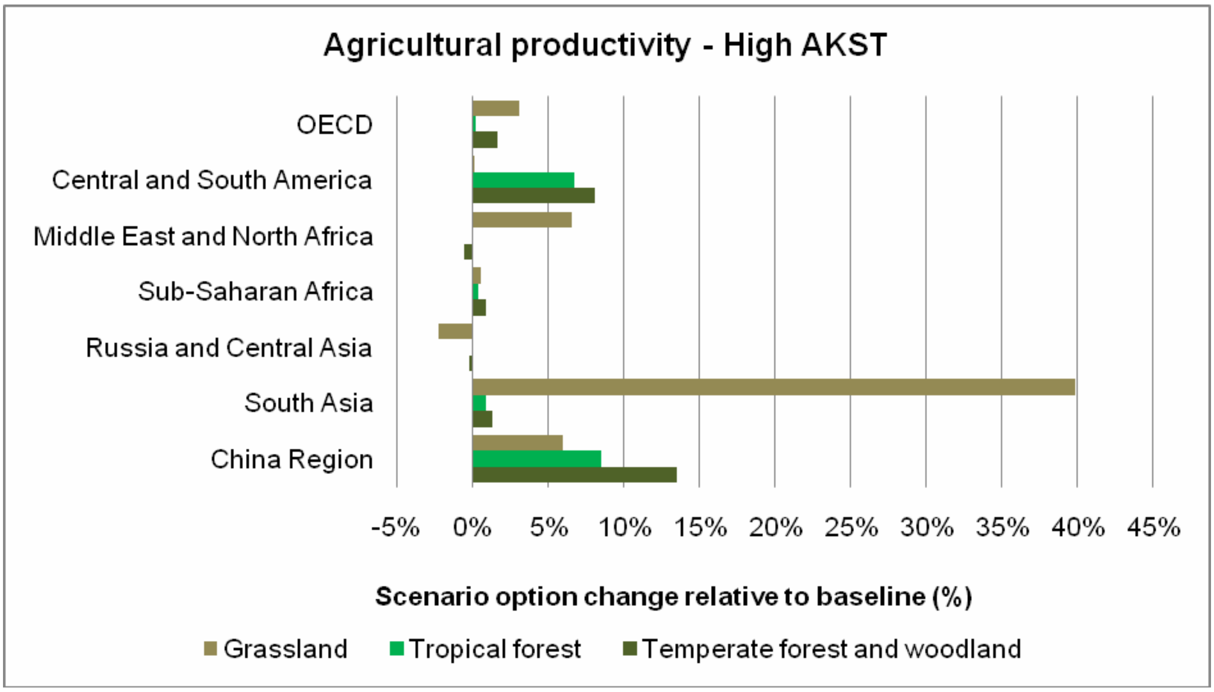

Figure 3 Agricultural productivity: change in area of biomes for high AKST scenario option relative to the baseline

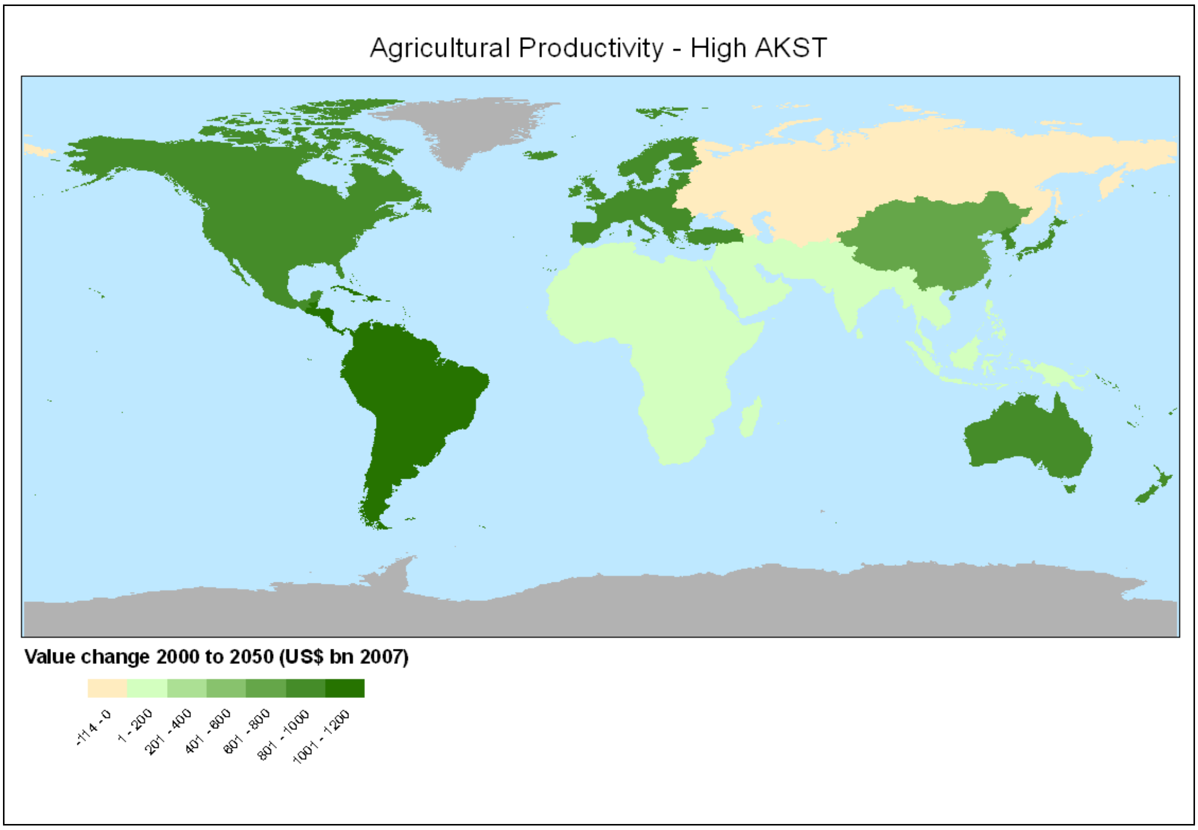

Figure 4 Agricultural productivity (high AKST): Map of value changes 2000 to 2050 applying a 1% discount rate

Note that Table 10 shows the breakdown on a biome-by-biome basis. Thus the sum of the value changes across the three biomes (US$23.4 billion 2007 for grasslands; US$89.6 billion 2007 for temperate forest; US$ 48.3 billion 2007 for tropical forests) are summed in the summary table (Table 11, second column, i.e. US$161.34 billion 2007). Further, the annual values for each region cannot be calculated directly from the changes in area and the mean per ha values. This is because the value functions include patch size as an explanatory variable, hence the value per ha varies across patches[9]. The patch size coefficient for each biome is negative indicating that larger patches have lower per ha values.

Table 10 Agricultural productivity: value results by region and by biome (high AKST)

	Change in area ('000 km^2)	Mean per ha value (US$ 2007)	Annual value (bn US$ 2007)
Grassland			
OECD	418.4	645.0	19.7
Central and South America	4.7	253.3	0.1
Middle East and North Africa	64.6	325.0	1.7
Sub-Saharan Africa	35.2	63.6	0.2
Russia and Central Asia	-198.2	351.2	-4.1
South Asia	461.1	146.1	4.3
China Region	81.5	232.2	1.5
Total	**867.3**		**23.4**
Temperate Forest			
OECD	181.1	23,389.1	28.8
Central and South America	57.0	19,630.4	21.2
Middle East and North Africa	-0.4	18,264.7	-0.2
Sub-Saharan Africa	2.4	9,033.3	0.2
Russia and Central Asia	-15.4	20,198.6	-2.1
South Asia	5.5	10,886.6	1.5
China Region	210.0	17,515.3	40.2
Total	**440.3**		**89.6**
Tropical Forest			
OECD	1.9	9,916.5	0.6
Central and South America	415.7	8,161.4	41.9
Middle East and North Africa			
Sub-Saharan Africa	21.1	3,897.4	0.8
Russia and Central Asia			
South Asia	20.7	7,376.6	3.2
China Region	8.0	8,370.8	1.7
Total	**467.6**		**48.3**

Mean per ha values are the average of 2050 baseline and 2050 scenario per ha values.

Total value changes are sum of individual patch values and are not calculated from regional mean per ha values

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[9] As an example, assume we have a region with three patches of biome X that are initially 100, 200 and 500 ha in size and the per ha values are $400, $300 and $200 respectively. Then if each patch increases by 10% the sum of the individual patch values is (10 x 400) + (20 x 300) + (50 x 200) = $20,000. If we use the total change in patch area and mean per ha values the estimated value would be (10 + 20 + 50) x 300 = $24,000.

Table 11 Annual and discounted aggregated regional benefits (billions 2007 US$) of agricultural productivity increase (high AKST investment versus BAU baseline)

	2050 undiscounted annual benefit	2000 – 2050 discounted total benefit		
		0%	1%	4%
OECD	49.13	1252.72	902.56	375.96
Central and South America	63.16	1610.50	1160.33	483.33
Middle East and North Africa	1.52	38.79	27.95	11.64
Sub-Saharan Africa	1.29	32.82	23.64	9.85
Russia and Central Asia	-6.18	-157.66	-113.59	-47.32
South Asia	9.03	230.17	165.83	69.08
China Region	43.41	1106.91	797.50	332.20
Total	**161.34**	**4114.24**	**2964.24**	**1234.74**

6 Discussion

Globally, the land cover value change is significantly positive, i.e. US$2964 billion 2007 at a 1% discount rate (see Table 11). The results show that there are significant welfare gains associated with the high AKST scenario across the three biomes; however there are some distributional issues across regions. Specifically the ‘Russia and Central Asia’ region sees a loss in welfare of US$6.2 billion 2007 per annum in 2050; this arises due to an expansion of agricultural production and improved growing conditions in that region (PBL, 2010).

Given the development-focused nature of the option scenario, the IMAGE regions that show the largest benefits from land cover change include ‘Central and South America’ ‘OECD’ and ‘China region’. These benefits arise largely from increased forest area relative to the baseline across these regions; although there are also substantial benefits from increased grassland area in the ‘OECD’ region.

Alongside the benefits from land cover change, the estimated net benefit (relative to the baseline) from additional carbon sequestration is valued at is US$471.8 billion 2007 (see **Error! Reference source not found.**). Cost estimates at 1% discount rate are estimated to be US$568.3 billion 2007. The benefit-cost ratios are set out in Table 12.

Even without adding the additional carbon storage estimated to occur with the option scenario, the benefit/cost ratio is significantly positive, i.e. 3.96 with higher 4% discount rate. The majority of the benefits from land cover change come from the forestry biomes: of the US$161.3 billion 2007 undiscounted annual benefit (see Table 11) 23.4 billion is attributed to the grasslands biome (see Table 10), i.e. 15%. This is significant: although one of the changes in the grasslands biome was arguably non-marginal (e.g. ~40% ‘South Asia’), the average change in the forestry biomes is 3%, i.e. clearly marginal. Even removing the grasslands benefits (US$686 bn) and the carbon benefits leaves a high benefit-cost ratio (~1.8 at 4% discount rate). We can say with high confidence that this option scenario is economically efficient on the basis of land cover change alone.

Our analysis combines a range of data sources to undertake a global assessment of the effects of increased investment in AKST. We drew on biophysical modelling by PBL (2010) to estimate the changes in land cover that arise from this policy. The costs of this investment were estimated from a review of existing literature. Finally we undertook meta-analyses of biome level valuation studies to estimate value functions for three terrestrial biomes. These value functions were then used in a global benefit transfer to individual patches of each biome.

Table 12 Overall benefit-cost ratios for option scenario 1: agricultural productivity (high AKST)

		Discount rate		
		0%	1%	4%
Benefits (bn US$2007)				
Change in biome areas		4,114.24	2,964.24	1,234.74
Carbon values (bn US$2007)				
	POLES	18,414.3	18,414.3	18,414.3
	SCC	6,342.8	6,342.8	6,342.8
	RICE high	3,843.6	3,843.6	3,843.6
	RICE low	1,384.6	1,384.6	1,384.6
Costs (bn US$2007)		725.0	568.3	311.5
Benefit/cost ratios				
No carbon value		5.67	5.22	3.96
Social Cost of Carbon		14.42	16.38	24.33
High carbon value (POLES model)		31.07	37.62	63.08
Low carbon value (RICE model low)		7.58	7.65	8.41

There are three constituent segments to the analysis of value changes that *cumulatively* describe whether or not a policy scenario is economically efficient: (1) the value in 2050 of land cover change that is predicted to occur with the policy scenario versus the 2050 baseline; (2) the value of changes in carbon storage arising with the policy scenario versus the baseline; and (3) the costs of implementing the policy scenario. An important point to be made with regards the estimation of any value changes is that our analysis partial for several reasons:

(1) In this study we focus on valuing changes in land cover, i.e. the *quantity* of a particular biome as opposed to the *quality* of the ecosystem (i.e. MSA). We do attempt to capture some aspects of changes in quality by testing various spatial variables which affect habitat quality in the derivation of the value functions, e.g. 'human appropriation of net primary product' as a proxy for intensity of land use and 'roads' as a proxy for habitat fragmentation. The outcome of this methodological choice is that the approach in our study is likely to systematically under-value changes in habitat quality.

(2) Aside from the results for carbon storage we do not attempt value transfer across ES categories. We use valuation estimates from primary studies once screened for methodological integrity, specificity of study area etc. But most data points in the valuation database are for study sites where only some subset of ESs has been valued. Since these site-level values are thus only partial this implies a systematic under-valuing of benefits. This second issue of omitted values for ES is generic to environmental valuation studies and to site-level benefits transfer (as opposed to ES-level transfer).

(3) Our value estimations for the policy scenario are based on changes to only three terrestrial biomes (temperate forest and woodland; tropical forest; and grasslands). It is very likely that there are significant value changes to other biomes.

These three factors contribute to a systematic under-representation of benefit estimates. Thus we contend that if benefits exceed costs then this is a *sufficient* condition to infer economic efficiency, but it costs exceed benefits we should be careful not to over-state the confidence we have in such outcomes.

Our results indicate that the benefit cost ratio for increased investment in AKST lies in the range 4 to 63 depending on choice of discount rate and carbon value. This suggests that this policy is economically efficient in terms of land cover change alone with net total benefits between 2000 and 2050 of between 1235 and 4114 billion US$2007.

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