Cost-effectiveness of climate-related agricultural investments in developing countries: a case study

GIACOMO BRANCA[AB], LESLIE LIPPER[B], ALESSANDRO SORRENTINO[A]

Jel classification: D62, O13, Q01, Q57

Abstract

Agriculture in developing countries requires substantial investments, public and private, to achieve food security. Climate-smart agriculture options would enhance the capacity of the agriculture sector to sustainably support food security, incorporating the need for adaptation and the potential for mitigation into development strategies. The paper discusses a two-phase interdisciplinary methodology based on a combination of biological and economic modeling. Agriculture investments which can deliver food security and adaptation benefits are tested for their mitigation potential using the Ex-ante Carbon balance Tool (Ex-act). Marginal abatement cost (MAC) curves are then built in order to identify the least cost options. The methodology can be applied to different environments and country contexts. A case study in Malawi is used as empirical application.

Keywords: *agriculture, food security, climate change, bio-economic modelling.*

Résumé

L'agriculture dans les pays en développement nécessite d'investissements importants, publics et privés, afin de garantir la sécurité alimentaire. L'agriculture intelligente face au climat permettrait de soutenir durablement la sécurité alimentaire, en intégrant l'adaptation et le potentiel d'atténuation dans les stratégies de développement. Cet article présente une méthode interdisciplinaire avec une combinaison de modélisation biologique et économique. Des investissements agricoles qui peuvent offrir des avantages en matière de sécurité alimentaire et d'adaptation sont testés pour leur potentiel d'atténuation à travers l'outil Ex-ante Bilan Carbone (EX-ACT). Les courbes de coûts marginaux de réduction sont ensuite construites afin d'identifier les options les moins coûteuses. La méthode peut être appliquée à différents environnements et contextes nationaux. Une étude de cas au Malawi est utilisée comme application empirique.

Mots-clés: agriculture, sécurité alimentaire, changement climatique, modélisation biologique et économique.

1. Introduction

The agriculture sector in developing countries is being called on to increase food production to meet the food demand and incomes for a growing population in a context of climate changes. This is particularly true in Africa as the Intergovernmental Panel on Climate Change (IPCC) predicts that Africa will be the region most affected by climate change, due to both changes in mean temperatures and rainfall, as well as increased variability associated with both (IPCC, 2007).

To achieve global development and food security objectives there is a need to transform agricultural systems, aiming to higher and more stable returns from agricultural production and more sustainable food systems, but different pathways to agriculture development exist. Past models of agriculture development (e.g. conventional agriculture intensification), albeit effective in increasing productivity, focused mostly on high potential production zones, were highly dependent on fossil fuels (conversion of energy sources from human to animal and fossil fuel dependent machinery, increased use of fertilizers, pesticides and herbicides), failed to also consider systems' resilience (expansion of agricultural land area through deforestation and conversion from grasslands to croplands) and generated significant environmental costs (e.g. depletion of natural resources – land, water, genetic resources – used in the production systems).

Alternatively, sustainable agriculture intensification models aim to increase productivity and reduce costs through the use of technologies and practices that increase efficiency of input use (energy, fertilizer, water), augmenting the role of ecosystem services in agricultural production systems, and reducing pollution. Key features include a focus on closing yield gaps on existing agricultural lands and thus reducing agricultural land expansion, conservation and sustainable use of natural resources in agricultural production systems, and judicious use of diversification strategies to increase risk-adjusted returns to agriculture.

Climate-smart agriculture (CSA) is one approach to achieving this, addressing the challenges of building synergies between the closely related factors of climate change mitigation, adaptation and productivity and income increase, and minimizing their potential negative trade-offs (FAO, 2010). CSA is aimed at increasing food security and climate change adaptation, but can generate environmental positive externalities in the form of climate change mitigation. The demand for climate change mitigation will have to be met largely by the energy sector, the main emitter. However, there is substantial mitigation potential in the agricultural sector: the technical mitigation potential of agriculture by 2030, considering all Greenhouse gases is estimated to be 6,000 MtCO_2e/year (Smith *et al.*, 2008) and 70 per cent of this potential could be realized in developing countries (FAO, 2009). This potential could be achieved in some cas-

---

[a] Correponding author: Dipartimento di Economia e Impresa (DEIM), Universitá della Tuscia, Via del Paradiso 47, 01100, Viterbo, Italy. E.mail: branca@unitus.it

[b] Agricultural Development Economics Division, FAO, Via delle Terme di Caracalla, 00100, Rome, Italy.

[a] Dipartimento di Economia e Impresa, Universitá della Tuscia, Via del Paradiso 47, 01100, Viterbo, Italy.

es through absolute reductions in Greenhouse gas (GHG) emissions – including removal through sequestration in agricultural soils, and below and above ground biomass – and through greater efficiency in agricultural production, therefore leading to fewer emissions per unit of product. Given the public goods nature of the mitigation benefit, government intervention, and financing, it is necessary to provide measures that internalize the value of the externality in the production decisions of farmers. CSA also offers the opportunity to provide agriculture sector in developing countries with additional financing sources. International climate finance is one source of funds which could potentially be used to reward the positive externalities of CSA (FAO, 2010).

Agriculture sector in developing countries requires in fact substantial investments, public and private, to increase agriculture productivity and achieve food security (Schmidhuber and Tubiello, 2007). However, planned investment expenditures are often higher than the available finance resources and additional funds are needed in order to fill the gap. For example, total agriculture investments in Africa, measured as gross capital formation only increased from US$20 billion to US$35 billion during the last three decades, corresponding to a decrease from 19 to 14% of GDP (UNCTAD, 2009). International climate finance is one potential means of filling this gap.

Climate finance still lacks an internationally agreed definition, but broadly speaking it refers to resources that catalyze low-carbon and climate-resilient development. Financing needs are related to creating an enabling environment including policy development and cross-sectoral planning; capacity building; research and technology transfer; and the implementation and monitoring of mitigation and adaptation practices. Examples of current and potential climate finance flows from developed countries include Clean Development Mechanism (CDM), Adaptation Fund, Green Climate Fund and concessional loans and grants related to agriculture-based mitigation and adaptation actions.

While there is a wide range of sustainable agriculture technical solutions readily available which could deliver CSA benefits, identifying which option is most efficient in any particular context is a critical necessity for effective policy-making under conditions of scarce investment resources.

This work proposes an ex-ante interdisciplinary methodology (combination of biological and economic modeling) for examining the potential of selected climate-smart activities within existing national agriculture investment plans to generate climate change mitigation benefits and helping policy makers to prioritize the different options on the basis of economic efficiency of GHG abatement. Cost-effectiveness of different options is proposed here as a possible eligibility criterion for climate-smart investments to enable access to existing, emerging and dedicated additional climate funds and financing mechanisms. The literature concerned with the cost-effectiveness of policy measures for the mitigation of GHG emissions in agriculture and forestry is wide (Povellato *et al.*, 2007). Both public and private dimensions of benefits and costs are considered: mitigation benefits (public good), investment (public) costs, and on-farm (private) benefits and costs. An empirical application of the methodology to the Malawi case study is then presented.

It should be specified that the methodology presented here can be easily applied to different environments and country contexts, especially to other African countries (e.g. those in the Mediterranean area) which would be under the same agricultural policy framework (i.e. the Comprehensive Africa Agriculture Development Programme - CAADP).

This paper is structured as follows. Section 2 provides a description of the analytical methodology and the data needed for its application. In section 3, the empirical application to a country case study and a crop (maize) selected as example is presented, and the results are discussed. The conclusions are reported in section 4.

2. Material and methods

2.1. Methodology

The paper proposes an innovative approach in which two different methodologies are combined:

(i) ex-ante estimation of the mitigation potential of climate-smart agriculture (CSA) investments using different land use scenarios and baseline emissions levels; and

(ii) identification of the most efficient solution by estimating the marginal abatement costs (MAC) of available options.

Even if the methodologies have been already developed elsewhere, as thoroughly described in what follows, they have been applied together for the first time in the present paper. A two-phase analytical methodology has in fact been adopted here: the unitary abatement potential of CSA technologies estimated through the first phase will represent the basis for computing the MAC curves in the second methodological step.

A second element of innovativeness of the present work is represented by its application to national agriculture investment plans which highlight policy priority areas for the development of African countries. Since such plans are developed and reviewed systematically, several perspectives for future wider application of the proposed methodology exist.

2.1.1. Estimation of mitigation potential of climate-related agriculture investments using the Ex-ante Carbon balance Tool (Ex-act)

Climate change mitigation benefits of climate-smart agriculture investment activities are estimated using the Ex-ante Carbon balance Tool (Ex-act) which can analyze the impact on GHG emissions and carbon sequestration of different land use scenarios. Ex-act has been developed using mostly the IPCC Guidelines for National Greenhouse Gas Inventories complemented with other methodologies and review of default coefficients for mitigation option as a base. The tool compares the baseline scenario ('without project', i.e. business as usual) and the 'with project' case, computing the Carbon-balance, selected as an indicator of mitigation potential. Duration of accounting is set at 20 years. Ex-act is a land-based accounting system, measuring Carbon stocks and stock changes per unit of land, as well as Methane (CH_4) and Nitrous Oxide (N_2O) emissions expressing its results in tonnes of Carbon Dioxide equivalent per hectare ($t\ CO_2e\ ha^{-1}$) and per year ($t\ CO_2e\ yr^{-1}$). The tool allows to model different climates and agro-ecologies (e.g. tropical, temperate, Mediterranean, etc.). A full description of the Ex-act structure and methodology can be found in Bernoux *et al.* (2010).

The output of this analytical phase is represented by an estimation of the environmental benefits of selected investment activities in the form of GHG abated and Carbon sequestered. This will represent the unitary abatement potential of each CSA technology which will be taken into account in the second methodological step.

2.1.2. Estimation of the MAC curves and identification of the least cost options

The second analytical phase consists of identifying the least cost mitigation options among a range of different CSA investments, by estimating a marginal abatement cost (MAC) curve.

MAC curves are built in order to identify the optimal (least cost) pollution control technology across a range of environmental media (Halsnæs *et al.*, 1994; McKitrick, 1999; Beaumont and Tinch, 2004).

Several examples of agriculture MAC curve analyses exist in the literature (McCarl and Schneider, 2001 and 2003; Deybe and Fallot, 2003; De Cara *et al.*, 2005; Pérez and Holm-Müller, 2005; US-EPA, 2005 and 2006; Weiske and Michel, 2007; Smith *et al.,* 2008; MacLeod *et al.*, 2010), while global GHG abatement cost curves for different sectors, including agriculture, can be found in McKinsey and Company (2010). However, the development of MAC modeling has been identified as one key area of research and policy advocacy relevant for the advance of the economics of climate change in agriculture (Wreford *et al.*, 2010).

MAC curves represent the relationship between the cost-effectiveness of different abatement options and the total amount of GHG abated and is upward-sloping, showing how marginal costs rise with the increase of the abatement effort, therefore indicating which solutions are most efficient. In this paper a 'bottom-up' approach is adopted and a MAC curve is derived by first identifying the variety of measures effective for generating increases in agricultural productivity and incomes, and then determining the spatial extent and cost of applying these measures across diverse farming systems that can characterize a country or region. This approach can deal with the heterogeneity of agriculture technologies, and with the variability in cost and abatement potential within different land use systems. The alternative 'top-down' MAC curve variant takes an externally determined emission abatement requirement that is allocated downwards through assumptions based on Computable General Equilibrium models, which in turn characterize industrial/commercial sectors according to production functions commonly applied throughout the sector. This approach implies a degree of homogeneity in abatement technologies and implementation cost which is not appropriate in agriculture, given the broad range of farming systems and cropping patterns existing even in areas characterized by the same agro-ecological conditions, with significant differences in terms of cost-effectiveness (Moran *et al.*, 2011).

MAC curves report costs of different abatement measures (per unit of CO_2e abated) on the vertical axis and the GHG volumes abated (annual emission savings generated by adoption of the measure) on the horizontal axis, showing a schedule of abatement measures ordered by their specific costs per unit of CO_2e abated estimated against what would be expected to happen in a 'business as usual' (BAU) baseline (Moran *et al.,* 2011). In this analysis, MAC curves report therefore only the incremental costs with respect to BAU scenario. Moving along the graph from left to right worsens the cost-effectiveness of technology options since each ton of CO_2e mitigated becomes more costly. It should be noted that some options may even show negative abatement costs (i.e. the adoption of such measures will increase profits, therefore showing a cost-saving technology opportunity).

A 'bottom-up' MAC curve for a selected case study is built here according to the following steps:

1. for each CSA investment typology taken into consideration and for which the annual mitigation benefits are computed (see phase 1 of the methodology), the flux of public and private costs and private expected benefits are estimated. Similarly to the climate change mitigation benefits, both adoption (investment and maintenance) costs and benefits are estimated against the 'business as usual' baseline scenario (incremental costs and benefits). This requires the definition of a counterfactual situation, represented by the current costs, revenues and profits[1];

2. on the basis of the flux of incremental benefits and costs estimated along the years, the net present value (NPV) is computed in order to analyze the profitability of the investment, and to take into account the timing of the benefit-

---

[1] It is worth to specify that marginality refers to the comparison between costs (and benefits) of selected technologies with respect to the conventional practice. Since technologies are considered as independent and without interaction ("stand alone" assumption), it is possible to estimate costs (and benefits) of each technology independently with respect to conventional practice. However, different technologies can also be examined by comparing the corresponding differences in marginal costs (and benefits).

costs flux (with respect to the realization of the investment). In fact, NPV represents the difference between the present value of the future cash flows from an investment and the amount of investment itself. Positive NPVs indicate that overall benefits are higher than the costs and that the investments are profitable. The present value of the expected cash flow is computed by discounting it using an appropriate rate of return[2];

3. cost-effectiveness of each technology option action will then be estimated (in terms of \$/t CO_2e abated). This will represent the marginal abatement costs of each option computed on the basis of the unitary abatement potential obtained in phase 1 of the methodology (through the ex-ante Carbon-balance tool).

2.2 Dataset

Different data sources provide the necessary information to be used when conducting the analysis following the methodology described above.

National agricultural investment plans provide an initial list of planned investments in the agriculture sector in selected countries with information about the corresponding investment costs and the targeted areas (investment size). The present analysis uses the dataset from the National Agriculture and Food Security Investment Plans (NAFSIPs) 2009-2013 developed under the Comprehensive Africa Agriculture Development Programme (CAADP). NAFSIPs report data about the typology and size of planned investment and the corresponding (public) costs of the investments for each of these pillars.

Expected (public) benefits in terms of annual climate change mitigation (carbon sequestered and GHG abated) in different climatic regions are expressed in units of CO_2 equivalent per hectare and per year and have been estimated using a dataset of coefficients from IPCC (2007). Such estimates were derived from studies conducted in regions throughout the world, standardized using a linear mixed – effect modeling approach and integrated by results of simulation models and represent average net mitigation through increase in the soil C stocks or N_2O and CH_4 emissions reductions (IPCC, 2007).

Available data on expected (private) benefits of selected CSA investment options focus mainly on the crop productivity increase consequent to investment implementation. There is a wide existing literature which shows the impact of agriculture mitigation technologies on the productivity (average yield) of crops and pastures. Specifically, the present analysis makes use of a dataset reporting the evidence base of the yield effects of selected cropland management practices in different climatic areas of developing countries and resulting from an extensive literature review (Branca *et al.,* 2013).

3. Empirical Application: the case of Malawi

In this section the application of the above described analytical procedure to a country case study is presented. Malawi has been selected as a case study. For the exemplificative purpose of the present analysis, only maize crop is taken into account (being the key food security crop in the country). The methodology has therefore been applied to a tropical agro-climatic context here, but it is suitable to be applied to different environment and agro-climatic conditions, since the dataset of technical mitigation coefficients has a global coverage.

3.1. Description, assumptions and analytical steps

3.1.1. Agro-climatic characteristics and mitigation potential

Agriculture, the mainstay of Malawi's economy and survival, is presently heavily dependent on climate, especially natural rainfall. Specifically, there is evidence that key crops (e.g. maize) may be severely affected by climate change. Malawi has in fact been experiencing declining maize yields in the past years. Yields may be very vulnerable to the projected climate change, in particular to a decrease in rainfall (MNREA, 2002).

The climate in Malawi changes from semi-arid in the Lower Shire Valley, semi-arid to sub-humid on the plateau and sub-humid in the highlands. Most of the country receives between 763-1,143 mm annual rainfall and almost 90% of rainfall occurs between December to March, with no rain at all between May to October over most of the country (Reynolds, 2006). Given the purpose of this analysis, a simplistic assumption that 40% of the country area falls within a tropical moist climate and 60% within a tropical dry climate is made. Dominant soil type is assumed to be High Activity Clay Soil (HAC), consistently with the FAO-Unesco Soil Map of the World. Annual average mitigation coefficients used in the analysis in each climate region for the above described sustainable land management options on HAC soils are reported in table 1.

3.1.2. Climate-smart agriculture investment options and targets

For the exemplificative purpose of the present analysis we focus here only on a sub-set of possible CSA investment options – i.e. the adoption of sustainable cropland management technologies – and to crops that are key for food security in the country (cereals and, specifically, maize). This assumption is arbitrary and reduced the number of measures that could be considered within the constraints of this exercise to a well defined set of technologies: (i) improved agronomic practices (e.g. crop rotations with legumes, good agricultural practices), (ii) integrated nutrient management (e.g. increased efficiency of fertilizers and organic fertilization), (iii) tillage and residue management (e.g. zero tillage, mulching), (iv) agroforestry, and (v) water management

---

[2] NPV is computed as follows: $NPV = \Sigma_t [(B_t - C_t) / (1 + r)^t]$ where B_t and C_t are the benefits and the costs referred to the year t, r is the discount rate and t the time considered (n. years).

Table 1. *Incremental annual mitigation and net private benefits by practice and agro-climatic zone.*

Climate zone	Sustainable land management technology	Unit annual average CO_2e savings	Target area	Total annual average CO_2e savings	Total capital cost	Yield increase with respect to conventional technologies	Incremental annual net benefits	Total Incremental annual net benefits
		(t/ha per year)	(ha)	(t/year)	(000$)	(%)	($/ha)	(000$)
Tropical-dry	Improved Agronomic Practices	0,25	1.920.000	487.200	138.586	137	94	181.313
	Integrated Nutrient Management	0,23	1.920.000	436.800	234.586	80	55	105.876
	Tillage and Residue Management	0,29	90.000	25.988	12.660	60	41	3.722
	Agroforestry	0,35	42.000	14.700	21.552	114	79	3.309
	Water Management	0,998	136.800	136.458	100.602	110	76	10.373
Tropical-moist	Improved Agronomic Practices	0,77	1.280.000	985.600	92.390	151	104	133.228
	Integrated Nutrient Management	0,48	1.280.000	616.000	156.390	114	79	100.583
	Tillage/Residue Management	0,61	60.000	36.750	8.440	90	62	3.724
	Agroforestry	0,72	28.000	20.160	14.368	87	60	1.679
	Water Management	0,998	91.200	90.972	67.068	90	62	5.658

(improved efficiency of irrigation schemes, rainwater harvesting systems).

Since limited information exists about the possible effects of combining different technologies, it is assumed here that these measures do not interact; therefore a "stand-alone" cost-effectiveness and GHG abatement potential of each measure will be computed. Private (on-farm) costs and benefits and their timing will also be computed by calculating the effect of "stand-alone" measures on farm gross margins using, when available, representative farms together with additional relevant information available in the literature. This represents a bias of the present analysis which would lead to under-/over-estimate abatement costs in case trade-offs/synergies respectively exist among the different practices.

Each CSA technology option is analyzed using targets (number of hectares where the investments will take place) reported in the NAFSIP, together with the corresponding investment costs over the 5-year analytical time-frame. The same targets are also adopted in order to estimate potential annual mitigation benefits (net annual CO_2 savings) of each selected technology. Target areas (by agro-climatic zone) considered in the analysis are reported in table 1. It is assumed that in each target area only one type of sustainable land management technology is adopted (for example, 'improved agronomic practices' will be implemented over 1.92 million hectares of tropical dry areas and 1.28 million hectares of tropical moist areas, the same will happen for 'integrated nutrient management' (but on different plots and in different zones[2]), 'tillage and residue management' on 90 thousand hectares and so forth.

In this sense technologies are considered as independent options and are not cumulative interventions. However, target areas (i.e. land plots where each technology is implemented) are considered as cumulative: total implementation area of proposed investments is computed as the sum of single target areas corresponding to each investment intervention.

3.1.3. Costs and benefits

There are five broad categories of costs/barriers identified in the literature associated with the adoption of sustainable land management practices and investments: investment costs, variable and maintenance costs, opportunity costs, transactions costs, and risk costs.

In this paper it is assumed that investment and transaction costs are borne by the public sector and coincide with the capital cost reported in the NAFSIP. Specifically, the capital cost will include costs of activities and material needed to: make improved technologies available at farm level (e.g. develop mother nurseries and vegetative multiplication, develop new varieties) and promote their dissemination (e.g. promote water users associations, developing extension services); conduct training and capacity building (e.g. strengthen technical capacity for irrigation management); rehabilitate infrastructure (e.g. irrigation schemes and structures, rainwater harvesting systems); build on-farm structures. Total (public) capital costs of planned investment considered in the analysis (by agro-climatic zone and for the maize sub-sector) are reported in table 1.

Variable and maintenance on-farm costs are recurrent expenses needed to either undertake a specific practice – such as purchase of seeds, fertilizers or additional hired labor – or periodic costs associated with maintaining on-farm structures. These costs are estimated on the basis of the literature available (Wocat, 2007; Ngwira *et al.*, 2012). Annual private (variable) costs of selected mitigation options are computed over a 5-year time frame against a 'business as usual' scenario (conventional practice) and are therefore only incremental costs (i.e. increased/decreased costs borne as a consequence of the implementation of the improved technology and computed with respect to the costs under conventional agriculture).

Opportunity costs are represented by foregone income that may arise with the adoption of sustainable land management activities. Since the analysis takes into account the costs increase related to the adoption of the new practices against the conventional technology (baseline), opportunity costs are already included. Also, for the sake of simplicity, the different risk magnitude (and relative costs) associated

---

[3] It is only a coincidence that the sizes of these interventions are identical.

to the different technology options are not taken into consideration.

Private on-farm benefits of implementing the different practices are computed by estimating the increased yield under the improved technology against the yields under conventional agriculture (and corresponding revenue increase, holding prices constant). Incremental yields obtained as a result of adoption of the improved agriculture technology come from the literature (Branca *et al*., 2013). Table 1 reports average yield increases per each practice against yields under conventional agriculture, together with the incremental on-farm annual (private) net benefits.

Since no information was available on the variance and probability distribution of farm data, only mean values are considered here. When computing the NPV of the investments, the rate of return is set equal to the GDP growth rate at constant prices, where expenditure-based GDP is computed as difference between total final expenditures at purchasers' prices (including the f.o.b. value of exports of goods and services) and the f.o.b. value of imports of goods and services. In the analysis, a 7% rate of return is used, based on the latest estimates available (6.6% in the year 2010) as estimated by IMF (2013).

3.2. Results and discussion

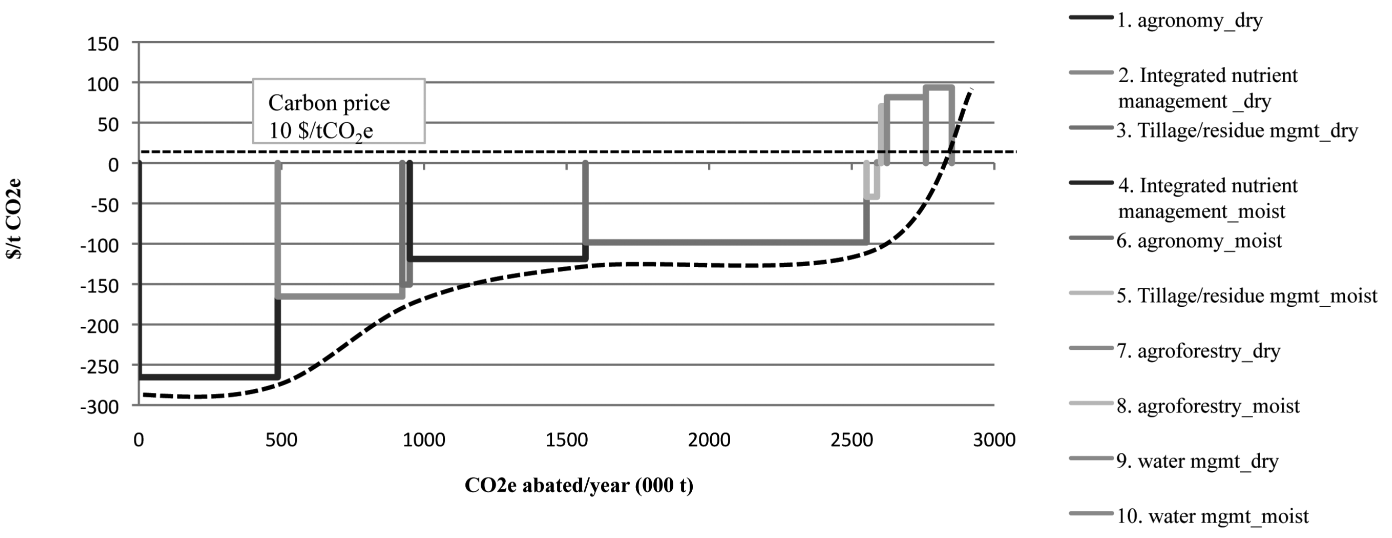
Estimation of the MAC curve related to the implementation of CSA investments in targeted areas requires an estimation of the flux of annual (private) incremental costs and benefits against the 'baseline' scenario (conventional practice). The stand-alone marginal abatement cost of a technology can be calculated by dividing the sum of capital cost and NPV of net benefits ($) by the abatement rate (t-CO_2e/year) over the land area where the specific practice will be implemented (table 2). The MAC curve for selected CSA practices in Malawi is reported in figure 1.

The MAC curve is derived as a histogram where each bar represents a single agriculture technology option. The width of the bar represents the amount of abatement potential (ton of CO_2e saved as measured on the x axis). This amount is computed multiplying the unit abatement potential (i.e. the "unit average CO_2e savings" reported in table 1 and expressed in ton of CO_2e abated per hectare) by the number of hectares where each technology is implemented

Table 2. *Cost-benefit analysis by practice and agro-climatic zone.*

Technology	Agro-climatic zone	Area	(Public) capital cost	(Private) annual net benefits	Annual average CO_2 savings	Net cost present value	Marginal abatement cost
		A	B	C	D	$E=B-\{Sum\ [C_t/(1+r)^t]\}$	$F = E/D/5$
		(ha)	(000$)	(000$)	(t CO_2e/year)	(000$)	($/tCO2e)
Improved Agronomic Practices	Tropical dry	1.920.000	138.586	181.313	487.200	-548.735.111	-225
	Tropical moist	1.280.000	92.390	133.228	985.600	-412.648.176	-84
Integrated nutrient management	Tropical dry	1.920.000	234.586	105.876	436.800	-287.176.107	-131
	Tropical moist	1.280.000	156.390	100.583	616.000	-301.154.482	-98
Tillage and residue management	Tropical dry	90.000	12.660	3.722	25.988	-15.560.285	-120
	Tropical moist	60.000	8.440	3.722	36.750	-5.670.142	-31
Agroforestry	Tropical dry	42.000	21.552	3.309	14.700	2.738.477	37
	Tropical moist	28.000	14.368	1.679	20.160	8.002.758	79
Water management	Tropical dry	136.800	100.602	10.373	136.458	61.281.737	90
	Tropical moist	91.200	67.068	5.658	90.972	45.620.584	100

Figure 1. *Marginal Abatement Costs curve for selected CSA practices in Malawi.*



(i.e. the "target area" reported in table 1 and measured in hectares). The height of the bar indicates the unit cost of the action (unit cost of abatement measured in US$ per ton of CO_2e saved as measured on the y axis) and the area (height * width) of the bar shows the total abatement cost of the technology (measured in US$). Although technologies are alternative options, the areas where such options are implemented can be added together. By summing up the areas of the bars it is therefore possible to derive the total abatement cost of a cumulative abatement target, measured in US$. Under these assumptions, total area shows the total abatement cost corresponding to the total CO_2 savings achievable by implementing all technology options on the target areas as indicated in the NAFSIP.

The bars have been placed in order of increasing unit cost. In other words, the technology with the lowest abatement cost is put as the first option, while the technology with the highest unit abatement cost is put as the last option. In this way the MAC curve shows the range of possible technology options that should progressively be implemented according to a criterion of cost-effectiveness. With reference to the case study, the adoption of improved agronomic practices in dry areas should be a priority as they represent the cheapest option. Therefore, in case policy makers are dealing with a budget constraint, as it is often the case, they should promote the adoption of this technology option first, in order to act in a cost-effective way. Public expenditure should be invested in the promotion of such alternative first (in this case, about 139 million US$ as indicated in column B of Table 2) in order to gain efficiency. Other options will be considered, according to the sequence of the bars, if the budget constraint is released.

The MAC curve is built using data reported in Table 2. The curve represents a useful way of showing the results as sustainable land management options have been placed in order of increasing unit abatement cost. For example this can be useful for policy makers wishing to choose the least cost option among the available climate-smart technologies. Second, the curve can be utilized to identify best investment options in case a market price for Carbon can be identified: for example, agroforestry and water management options would be too costly to be remunerative at an hypothetical price of 10$/ton CO_2e. Third, the curve can be useful to simulate policy measures, such as the amount of a subsidy to be paid to farmers to promote the adoption of costly land management options (e.g. water management would be more expensive than conventional agriculture and farmers would need proper incentives to adoption).

The MAC curve developed in the case-study is based only on average values[3] and it does not take into account the variability of farms and agro-ecosystems existing in the country. While this clearly represents an oversimplification, the analysis produced interesting results. The MAC curve shows that marginal abatement costs are negative for improved agronomic, integrated nutrient management and tillage/residue management practices, in both dry and humid areas (although with differences among the technologies and the agro-climatic zones). Adoption of the improved practices will in fact generate gross margins higher than under conventional agriculture, therefore showing a synergy between rural development (increased food security) and climate change mitigation (abatement potential).

These technology options can therefore generate both private and public benefits and thus constitute a potentially important means of generating "win-win" solutions to addressing poverty and food insecurity as well as environmental issues (climate change mitigation). Such practices contribute to improving soil fertility and structure, adding high amounts of biomass to the soil, causing minimal soil disturbance, conserving soil and water. This in turn translates into better plant nutrient content, increased water retention capacity and better soil structure, leading to higher yields and greater resilience, thus contributing to enhancing food security and rural livelihoods (FAO, 2009).

An important word of caution is needed when considering this MAC analysis in that it is difficult to effectively capture the full range of public and private costs that would be entailed in adopting the practices screened. One of the main issues is the presence of a significant delay (some years) before positive benefits can be realized for many practices and situations, which is a significant barrier to adoption given thin credit markets.

Also, there is often limited information and experience with alternative techniques that hinders adoption, particularly given insurance markets that are even more thin – or non-existent – than credit markets. Even where farmers might invest in certain techniques, inputs are often not available in local markets. Public funding covering some of these investment costs and financing information and capacity building may help overcoming such barriers.

The second set of technologies shown in the MAC curve (agroforestry and water management) is found to have positive abatement costs (costs higher than benefits). This is probably due to the fact that this type of investments requires bigger investment costs (irrigation infrastructures, water harvesting land structures, seedlings production and planting). Also, they are characterized by a longer implementation period where the costs are borne in the first years (building infrastructure and planting trees), while the benefits are gained in the medium-long term, therefore generating a negative flux of net benefits in the short-term (like the 5-year time frame of the present analysis).

The results are based on plausible but arbitrary assumption regarding discount rate. This assumption was subjected to sensitivity analysis to test the robustness of the results. Abatement costs were calculated at discount rates of 5 per cent, 10 per cent and 15 per cent. Results of the sensitivity analysis are presented in table 3. The abatement costs are, as expected, negatively related to discount rates and show variations consistent with the changes in the rates (table 3) confirming the robustness of the analysis.

---

[4] Unit marginal abatement cost is held constant within each sustainable land management option and it is equal to the average difference between the cost for that specific technology and the cost for the conventional practices. However average unit costs vary among the technology options, as shown by the MAC curve which in fact is a broken line.

Table 3. *Sensitivity analysis.*

Technology	Agro-climatic zone	Marginal abatement cost (000$/ton) at discount rate			
		7%	5%	10%	15%
Improved Agronomic Practices	Tropical dry	-248,3	-265,4	-225,3	-192,6
	Tropical moist	-92,1	-98,3	-83,7	-71,9
Integrated nutrient management	Tropical dry	-151,0	-165,4	-131,5	-103,8
	Tropical moist	-109,9	-118,9	-97,8	-80,6
Tillage and residue management	Tropical dry	-137,5	-150,6	-119,8	-94,6
	Tropical moist	-37,1	-41,8	-30,9	-22,0
Agroforestry	Tropical dry	16,4	20,9	37,3	66,9
	Tropical moist	74,2	70,4	79,4	86,7
Water management	Tropical dry	85,1	81,6	89,8	96,5
	Tropical moist	96,4	93,6	100,3	105,8

4. Conclusions

In order to achieve global development and food security objectives there is the need to transform agricultural systems, aiming for higher and more stable returns from agricultural production and more sustainable food systems. Different pathways to agriculture development exist and CSA is an approach to building the necessary policy, financing and evidence base to achieve sustainable agriculture intensification under climate change. CSA options showing a win-win potential between increased productivity and climate change adaptation on one side, and mitigation on the other side would in fact enhance the capacity of the agriculture sector to sustainably support food security, incorporating the need for adaptation and the potential for mitigation into development strategies.

However, these results are solely indicative of activities that may be considered for more detailed analysis, focusing particularly on the public and private costs to overcoming barriers to the adoption of such practices: e.g. opportunity costs of land and labor including up-front cash outlays; limited information available about alternative techniques as well as limited local experience with such practices; problems related to access to inputs and to property rights of the resources. Agriculture investments are largely privately financed but the public sector could help overcome such adoption barriers, covering investment and transaction costs (e.g. supporting research, development and capacity building). As long as there is evidence of the mitigation benefits generated by the implementation of CSA, international climate finance could help by filling the existing financing gaps of the plans for public investments. The role of international public sector intervention could be to support mechanisms that internalize positive externalities (climate change mitigation) in production decisions of farmers: through CSA, international public funds invested for mitigation activities (public good) could leverage private investments aimed at increasing the adaptive capacity (private good) of agricultural systems. In fact, where adaptation and mitigation practices can increase the returns to or reduce the risk of agriculture investments, and where mitigation benefits can be accounted for and create an additional asset return from the investment, climate finance may increase the attractiveness to the private sector of investment in agriculture. For example, climate finance could be used to provide loan guarantees for investments with high upfront payments and delayed benefits. Climate investments in the sector could benefit small rural households to increase or at least stabilize their capital stocks, contributing to accelerated agriculture-led economic development and poverty reduction. However, well-designed national climate-related policies should orient agriculture sector development towards the adoption of climate-smart technologies and production, in line with the climate policy goals under definition at international level.

To this extent, the methodology proposed here may represent a useful instrument which national policy makers could use to orient their choices. For example, the empirical application to the case-study indicates that most CSA technologies can potentially generate gross margins higher than those under conventional agriculture (negative marginal abatement costs), showing synergies between rural development and climate change mitigation. Appropriate policies to promote the adoption of such technology packages should therefore be promoted at national level.

The methodology has been applied to a tropical environment, but the analysis could easily be replicated for other climate and agro-climatic country contexts. Nevertheless, more research is needed in order to refine the methodology and to provide more country-specific data inputs and generate more in-depth estimates of technology options' cost-effectiveness. For example, rather than one MAC curve based on a limited set of climate characteristics (dry/moist areas), several MAC curves can be defined to cover different categories of farm types, regional environments, agro-ecological zones and farming systems, although such disaggregation would raise a further challenge in relation to data availability. The identification of apparent win-win measures also suggests that there is a need for understanding farmer behaviours in relation to the management of GHG emissions.

References

Beaumont N.J. and Tinch R., 2004, Abatement cost curves: a viable management tool for enabling the achievement of win-win waste reduction strategies? *Journal of environmental management,* 71(3): 207-215.

Bernoux M., Branca G., Carro A., Lipper L., Smith G. and Bockel L., 2010, Ex-ante greenhouse gas balance of agriculture and forestry development programs, *Scientia Agrícola* 67: 31-40. doi: 10.1590/S0103-90162010000100015

Branca G., McCarthy N., Lipper L. and Jolejole M.C., 2013. Food security, climate change and sustainable land management. A review, *Agronomy for Sustainable Development*, 33(4): 635-650. doi: 10.1007/s13593-013-0133-1.

De Cara S., Houzé M. and Jayet P.A., 2005. Methane and nitrous oxide emissions from agriculture in the EU: a spatial assessment of sources and abatement costs. *Environmental and Resource Economics,* 32: 551-583.

Deybe D. and Fallot A., 2003. Non-CO$_2$ greenhouse gas emissions from agriculture: analysing the room for manoeuvre for mitigation, in case of carbon pricing. In: *25th International Conference of Agricultural Economists, August 16th - 22th, 2003, Durban.*

FAO, 2009, *Food security and agricultural mitigation in developing countries: options for capturing synergies*, [Available at] www.fao.org/docrep/012/i1318e/ i1318e00.pdf [Accessed 30 July 2014]

FAO, 2010, *Climate-smart agriculture. Policies, practices and financing for food security, adaptation and mitigation*, [Available at] www.fao.org/docrep/013/i1881e/i1881e00.htm [Accessed 30 July 2014]

Halsnæs K., Mackenzie G.A., Swisher J.N., Villavicencio A., 1994. Comparable assessment of national GHG abatement costs. *Energy policy,* 22(11): 925-934.

IMF, 2013. *World economic outlook pril 2013: hopes, realities, risks*, [Available at] www.imf.org/external/pubs/ft/weo/2013/01/index.htm [Accessed 20 July 2013]

IPCC, 2007, *Climate change 2007, fourth assessment report, contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change*. Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E. (eds.). Cambridge: Cambridge University Press.

MacLeod M., Moran D., Eory V., Rees R.M., Barnes A., Topp C.F.E., Ball B., Hoad S., Wall E., McVittie A., Pajot G., Matthews R., Smith P. and Moxey A., 2010, Developing greenhouse gas marginal abatement cost curves for agricultural emissions from crops and soils in the UK. *Agricultural Systems,* 103: 198-209.

McCarl B.A. and Schneider U., 2001, Greenhouse gas mitigation in U.S. agriculture and forestry. *Science*, 294: 2481-2482. doi: 10.1126/science.1064193.

McCarl B.A. and Schneider U., 2003. Economic potential of biomass based fuels for greenhouse gas emission mitigation. *Environmental and Resource Economics,* 24(4): 291-312.

McKinsey and Company, 2010. *Impact of the financial crisis on carbon economics: Version 2.1 of the global greenhouse gas abatement cost curve.* [Available at] www.mckinsey.com/ [Accessed 26 August 2013].

McKitrick R., 1999. A Derivation of the marginal abatement cost curve, *Journal of environmental Economics Management,* 37: 306-314. doi:10.1006/jeem.1999.1065.

MNREA, 2002. *Initial national communication of Malawi*. Lilongwe, Malawi, Ministry of Natural Resources and Environmental Affairs, Environmental Affairs Department. [Available at] www.ndr.mw:8080/xmlui/handle/123456789/626 [Accessed 20 July 2014]

Moran D., Macleod M., Wall E., Eory V., McVittiel A., Barnes A., Rees R., Topp C.F.E., Pajot G., Matthews R., Smith P. and Moxey A., 2011, Developing carbon budgets for UK agriculture, land-use, land-use change and forestry out to 2022. *Climatic Change,* 105:529–553. doi 10.1007/s10584-010-9898-2.

Ngwira A., Aune J.B. and Mkwinda S., 2012. On-farm evaluation of yield and economic benefit of short-term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research*, 132:149-157. doi: 10.1016/j.fcr.2011.12.014.

Pérez I. and Holm-Müller K., 2005. Economic incentives and technological options to global warming emission abatement in European agriculture. In: *89th EAAE Seminar: Modelling agricultural policies: state of the art and new challenges, February 3-5th, 2005 Parma.*

Povellato A., Bosello F. and Giupponi C., 2007. Cost-effectiveness of greenhouse gases mitigation measures in the European agro-forestry sector: a literature survey. *Environmental Science & Policy,* 10:474-490. doi:10.1016/j.envsci.2007.02.005.

Republic of Malawi, 2010. *The Agriculture Sector Wide Approach (ASWAp), Malawi's prioritized and harmonized Agricultural Development Agenda.* [Available at] www.caadp.net/pdf/Investment%20plan%20-%20Malawi.pdf [Accessed 12 July 2013].

Reynolds L., 2006. *Country pasture/forage resource profiles: Malawi*. Rome: FAO. [Available at] http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Malawi.pdf [Accessed 12 July 2013].

Schmidhuber J. and Tubiello F.N., 2007. Global food security under climate change. *PNAS*, 104(50): 19703-19708.

Smith P., Martino D., D. *et al*., 2008. Greenhouse gas mitigation in agriculture. *Philos. trans. R. Soc. Lond., B*, 363(1492): 789-813. doi: 10.1098/rstb.2007.2184.

US-EPA, 2005. *Greenhouse gas mitigation potential in U.S. forestry and agriculture*, EPA 430-R-05-006. Washington, DC: U.S. Environmental Protection Agency. [Available at] www.epa.gov/sequestration [Accessed 26 July 2013].

US-EPA, 2006, *Global mitigation of non-CO_2 greenhouse gases*. United States Environmental Protection Agency, EPA 430-R-06-005, Washington, D.C. [Available at] www.epa.gov/nonco2/econ-inv/downloads/GlobalMitigationFullReport.pdf, [Accessed 26 July 2013].

UNCTAD, 2009. *World investment report 2009: transnational corporations, agricultural production and development*. [Available at] www.unctad.org/en/docs/wir2009_en.pdf [Accessed 20 August 2013].

Weiske A., Michel J., 2007. *Greenhouse gas emissions and mitigation costs of selected mitigation measures in agricultural production.* [Available at] www.ieep.org.uk/ assets/589/wp3__d15a__ghg_and_mitigation.pdf [Accessed 20 August 2013].

WOCAT, 2007. *Where the land is greener. Case studies and analysis of soil and water conservation initiatives worldwide.* Liniger H. and Critchley W. (eds.). [Available at] www.odi.org.uk/resources/docs/2662.pdf [Accessed 20 August 2013].

Wreford A., Moran D., Adger N., 2010. *Climate change in agriculture. Impacts, adaptation and mitigation.* OECD. [Available at] www.fao.org [Accessed 20 August 2013].