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Economics of Land Degradation Initiative: Methods and Approach for Global and National Assessments

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Abstract

Healthy land ecosystems are essential to sustainable development, including food security and improved livelihoods. Yet, their key services have usually been taken for granted and their true value underrated, leading to land degradation becoming a critical global problem. This pattern of undervaluation of lands is about to change in view of the rapidly rising land prices, which is the result of increasing shortage of land and high output prices. Despite the urgent need for preventing and reversing land degradation, the problem has yet to be appropriately addressed. Policy actions for sustainable land management are lacking, and a policy framework for action is missing. Such a framework for policy action needs to be supported by evidence-based and action-oriented research. The Economics of Land Degradation (ELD) initiative seeks to develop such a science basis for policy actions to address land degradation.

The purpose of this methodological paper is to provide with sound and feasible standards for ELD assessment at global and national levels. Only if some basic standards are identified and adhered to, comparative assessments can be conducted between countries and useful aggregation of findings, based on these case studies, can be achieved. Therefore, using the Total Economic Value (TEV) framework, the paper identifies minimum core standards that need to be adhered to in all country case studies to generate comparable material for international assessment and ELD policy guidance. It also identifies additional and desirable areas of information and analyses that would add value to the country case study material. The proposed framework is also intended as a forward-looking agenda which can guide future research.

Key words: Economics of Land Degradation, ELD, case studies, Total Economic Value

JEL classification: B41, Q01, Q15, Q24, Q51

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List of Abbreviations

AFSIS	Africa Soil Information Service
AVHRR	Advanced Very High Resolution Radiometer
BMZ	German Federal Ministry for Economic Cooperation and Development
CIESIN	Center for International Earth Science Information Network, Columbia University
ELD	Economics of Land Degradation
EU	European Union
FAO	United Nation’s Food and Agriculture Organization
GADM	Database of Global Administrative Areas
GDP	Gross domestic product
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	Geographic Information System
IIASA	International Institute for Applied Systems Analysis
ISRIC	International Soil Reference and Information Center
IFPRI	International Center for Food Policy Research
ITU	International Telecommunication Union
LCA	Life Cycle Analysis
NDVI	Normalized Differenced Vegetation Index
NGO	Non-Governmental Organization
NENA	Near East and North Africa
NOAA	U.S. National Oceanic and Atmospheric Association
NPP	Net Primary Production
PBL	Netherlands Environmental Assessment Agency
PES	Payment for Ecosystem Services
SSA	Sub-Saharan Africa
SLM	Sustainable Land Management
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Program
USD	United States Dollars
USDA-NRCS	United States Department of Agriculture, Natural Resources Conservation Service
SRTM	Shuttle Radar Topography Mission
TEV	Total Economic Value
YCEO	Yale Center for Earth Observation
WRI	World Resources Institute
ZEF	Center for Development Research, University of Bonn

INTRODUCTION AND PROBLEM DEFINITION

Purpose

The purpose of this paper is to provide sound and feasible standards for a national and global assessment approach of the economics of land degradation (ELD). Only if some basic standards are identified and adhered to, comparative assessments can be conducted between countries and useful aggregation of findings, based on these case studies, can be achieved. This is quite important for making impact on policy for investment and land use, and for getting land degradation problems out of their current obscurity. The key objective of this global ELD assessment is, therefore, to provide a comprehensive, consistent and feasible framework for guiding comparable national/regional ELD case studies that support policy actions to combat land degradation. The presented paper also seeks to raise international awareness about the need to compare multi-dimensional degradation costs between the scenarios of action and inaction against land degradation as the basis for creating incentives for social combating of land degradation.

The desirable ELD assessment framework and its implementation require answers to the following **research questions**:

i) What are key causes of land degradation across typical socio-ecological regions of the world?

ii) What are the economic, social and environmental costs of land degradation and net benefits resulting from taking actions against degradation compared to inaction?

iii) What are the feasible policy and development strategies that enable and catalyze sustainable land management (SLM) actions?

The ELD research seeks to test two **hypotheses**. Firstly, we test which geographic, demographic, economic, technological, institutional and cultural factors, such as climate and agricultural practices, population density, poverty, absence of secure land tenure, lack of market access and others, are significant causes of land degradation. Secondly, we also hypothesize that benefit of taking action against land degradation through SLM measures is greater than costs of inaction.

This paper proposes **analytic concepts and methods** to collate and analyze data to answer the above questions and test the proposed hypotheses at national and global scales. The paper identifies minimum core standards that need to be adhered to in all country case studies to deliver comparable material for international assessment and ELD policy guidance. It also identifies additional and desirable areas of information and analyses that would add value to the country case study material. However, there are tradeoffs between level of investment, sophistication, and timely material that can prompt an immediate action. This framework for ELD assessment does not imply that there are no other useful study approaches to address land degradation (for example, Noel and Soussan 2010). The approaches presented here build further and implement the analytical framework of ELD proposed by Nkonya et al. (2011), by also incorporating the feedback received thus far from various stakeholders. Readers interested in getting more information on the review of previous literature on economic assessment of land degradation, the detailed conceptual framework proposed for the global ELD assessment, and an overall background of this ELD research are referred to studies by Nkonya et al. (2011) and von Braun et al. (2013).

The expected outputs of the global study are summarized in Table 1. However it should be noted that due to time and financial resource constraints, this study *per se* is not meant to provide outputs to cover the entirety of the conceptual framework and methods it proposes, but will focus specifically on some core research agenda, also specified in this paper, with guidance for future complementary research.

Table 1. Planned outputs of the ELD assessment

#	Outputs	Brief Description
1	Conceptual paper on global ELD methodology	This corresponds to the present conceptual paper and provides with a toolbox of core and additional methodological approaches for conducting comparable country-level case studies.
2	Global mapping of land degradation hotspots	This work, and the related paper, will improve on previous global assessments and mapping of land degradation, by accounting for the masking effects of rainfall dynamics, atmospheric fertilization, and also indicating areas where high chemical fertilizer application may likely be masking the underlying land degradation processes.
3	Empirical modeling of impacts of various land management practices on major crop yields in different agroecological zones of the world	The empirical models will be developed showing the impacts of land degradation and of sustainable land management practices on crop yields in different agroecological zones of the world. The results will be published in a paper.
4	Technical discussion papers on the results of each case study	These will present the results of the country case studies implementing the analytical framework and core empirical methods presented here in this conceptual paper.
5	Country policy briefs on case study results	These research-based policy briefs are targeted to the policy makers but will also be useful for sharing with the media and the general public. They will present the key findings of country case studies in a non-technical language.
6	A documentary video on land degradation	This popular documentary video on the impacts of land degradation will be developed to raise awareness, catalyze social mobilization and policy commitment for action against land degradation
7	ELD data repository	All data collected under this study, subject to the data sharing protocols and permissions, will be made publicly available online
8	Final book on the ELD assessment	This publication will summarize the results of the study

Source: the authors

This ELD assessment is expected to make several **new contributions** to the research and practice of addressing land degradation. First, applying latest methodological advances (Vlek et al. 2010) and using remote sensing data, we identify global hotspots of land degradation. In doing so, we also account for the masking effect of atmospheric fertilization, thus improving on the previous efforts on global land degradation mapping. Secondly, we conduct a series of representative country case studies across the world using the standard core methods, thus allowing for comparability of the results and drawing of more generalizable conclusions. There have been numerous but isolated attempts in the past to assess the causes and consequences of land degradation. However, the differences in concepts and methodologies did not allow for their meaningful comparison, and quite often has led to contradicting policy conclusions (cf. Table 4 for examples). Thirdly, in contrast to the common practice in the economic assessment of land degradation-related problems, we do not limit our analysis to only on-site direct market-priced costs of land degradation, but apply the Total Economic Value (TEV) framework, seeking to comprehensively account for on-site and off-site, direct and indirect costs, including the losses in ecosystem services due to land degradation. Finally, we extend the analysis to impacts of land degradation on poverty and food security in the case study countries. Past land degradation economic assessments were limited to agricultural production despite tangible and deep impacts of land degradation on essential aspects of sustainable development such as food security and national welfare (Foley et al. 2005)

Problem Definition

Healthy land ecosystems (hereafter referred as "land") - which are well-functioning to ensure their services - are essential to sustainable development, including food security and improved livelihoods. Yet, key services of our lands have usually been taken for granted and their true value – beyond the market value – is being underrated (von Braun et al. 2013). This pattern of undervaluation of lands is about to change in view of the rapidly rising land prices, which is the result of increasing shortage of land and high output prices (ibid.). Moreover, the value of land ecosystem services is being better understood and increasingly valued. Globally, it is estimated that about a quarter of used land is degraded, affecting more than a billion people all over the world (Lal et al. 2012). Land degradation is defined as the persistent reduction of land's biological and/or economic production capacity, or as the long-term loss of land ecosystem functions and services (Safriel, 2007; Vogt et al., 2011). Land degradation has its highest toll on the livelihoods and well-being of the poorest households in the rural areas of developing countries (Nachtergaele et al. 2010). Vicious circles of poverty and land degradation, as well as transmission effects from rural poverty and food insecurity to national economies, critically hamper their development process.

Despite the urgent need for preventing and reversing land degradation, the problem has yet to be appropriately addressed (Lal et al. 2012). Policy actions for SLM are lacking, and a policy framework for action is missing (Nkonya et al. 2011). Such a framework for policy action needs to be supported by evidence-based and action-oriented research (von Braun et al. 2013). The past studies on land degradation had played a useful role in highlighting land degradation as a globally profound issue. However, most of them tended to ignore the above complexity and have focused on a simpler relationship (i.e. soil erosion and its impact on crop yield). Recent developments in simulation and data availability can help address more rigorously this complex relationship of land degradation. The losses from land degradation include not only environmental degradation cost measured directly on-site (e.g., soil loss and nutrient depletion), but also the cost of indirect and off-site environmental impacts (e.g., siltation of water bodies, water pollution, and biodiversity declines) (Foley et al. 2005).

Yet it is empirically challenging to account for all the costs of land degradation. Among major challenges are measurement and valuation of losses in ecosystem benefits due to land degradation (Barbier 2011a, 2011b). Moreover, the double-counting of these ecosystem benefits needs to be avoided – a complex task by itself (Barbier 2010). Processes (e.g. water purification) and benefits (e.g. purified potable water) could be double counted if each is given a separate value (Balmford et al 2008). The benefits are the end products of the beneficial processes. One approach to avoid double counting in this regard is to only take the value of potable water with different qualities and skip counting of the water purification process. However, it is equally obvious that the conceptual framework for Economic Assessment of Land Degradation should not be limited to only more easily measurable direct on-site and off-site costs of land degradation since taking such an approach ignores the intrinsic relationship of ecosystems and will lead to undervaluing the cost of land degradation and benefits of taking action against land degradation. Hence the conceptual framework should be able to accommodate all losses due to land degradation, thus providing guidance and basis for a comprehensive evaluation, even if it means that empirical gaps will be filled not immediately but through a longer-term research.

This action-oriented focus and the definitions of land and land degradation determine the methodological approaches of the ELD analysis. United Nations Convention to Combat Desertification (UNCCD) (1996) defines land as a terrestrial ecosystem consisting of flora, fauna, hydrological processes and other ecological services beneficial to human beings. The Millennium Ecosystem Assessment (MA 2005) defines land degradation as long-term loss of on-site and off-site terrestrial ecosystem goods and services, which humans derive from them. These definitions lead to using a comprehensive approach which takes into account both short- and long-term direct and indirect, on-site and off-site benefits of sustainable land management versus the related costs of land degradation. Thus, to be comprehensive, this economic assessment study uses TEV approach, which assigns value to all use and non-use ecosystem services (see conceptual framework below). This means the TEV approach captures the value of ecosystem goods and services and goes beyond the common monetary values of provisioning services used in many past economic studies. Consequently, we strive to capture all changes, both degradation and improvement, in ecosystem functions and services attributed to land ecosystems.

The action against land degradation involves preventing the degradation of currently used or usable lands or rehabilitating degraded lands. We refer to action against land degradation as sustainable land management, which according to TerrAfrica (2006), is generally understood as the “adoption of land systems that, through appropriate management practices, enables land users to maximize the economic and social benefits from the land, while maintaining or enhancing the ecological support functions of the land resources.” However, this definition is too general, lacking measurable criteria to guide policy focuses regarding SLM. In this study, we define “actions against land degradation” as land management which leads to persistent improvement of biological productivity and biodiversity of the land. However, relevant understanding of these criteria has to be based on the usage people expect from the land (i.e., expected land use) and the baseline for assessment.

(1) With land intentionally used for agricultural or forest production, long-term soil-driven net primary productivity (NPP), i.e. the net biomass produced by the soil and other natural resources (water and sunlight) without remarkable external inputs (e.g., improved rainfall, fertilizer use, atmospheric fertilization), can be a proxy for SLM or land degradation assessment. However, the treatment of observed biomass productivity trend has to further depend on the baseline of the assessment. Where the initial productivity was already low (degraded), a *long-term improvement* of soil-driven productivity can reflect SLM. Where the beginning productivity was already high, *at least an absence of decline* (a steady state) of soil-driven productivity also may indicate SLM.

(2) On land used/planned for nature protection, soil-driven NPP is still important, but biodiversity is an additional criterion for SLM. In many cases soil quality and biodiversity support each other, but in some other cases, they may not necessarily be mutually consistent. For example, an invasion of exotic plant species can lead to high biomass productivity but dramatically reduce biodiversity, which is not desirable. Increasing of soil nutrients can reduce plant diversity in some cases (Chapin et al. 2000, Sala et al. 2000, Wassen et al. 2005). The use of soil-based biomass productivity to indicate land degradation in these areas may not be relevant to the land-use goal. To include these areas in the land degradation or SLM assessment, in addition to soil resources, other foundational aspects of forest ecosystems (e.g. flora and fauna structures

and composition) have to be considered. Thus, using biomass productivity trend alone to indicate land degradation or SLM on such protected areas can give misleading results. Further, there is still a lack of data to more accurately delineate global forest cover into different use regimes.

This improvement is generally recognized as being closely determined by the increasing of net primary productivity (NPP) of the land, under certain conditions, and the improvement of soil fertility. The NPP trend, approximated by the trend of inter-annual Normalized Difference Vegetation Index (NDVI), can be an indirect indicator of soil degradation or soil improvement if the nutrient source for vegetation/crop growth is *solely*, or *largely*, from the soils (i.e., soil-based biomass productivity). In the agricultural areas with intensive application of mineral fertilizers (i.e. fertilizer-based crop productivity), NPP trend (via NDVI trend) principally cannot be a reliable indicator of soil fertility trend (Le 2012a). In this case, alternative indicators of soil fertility should be used. Moreover, the elevated levels of CO_2 and NO_x in the atmosphere (Reay et al. 2008, WMO 2012) can cause a divergence between NPP trend and soil fertility change as the atmospheric fertilization effect has not been substantially mediated through the soil. The rising level of atmospheric CO_2 stimulates photosynthesis in plants' leaves, thus increasing NPP, but the soil fertility may not necessarily be proportional to the above ground biomass improvement. The wet deposition of reactive nitrogen and other nutrients may affect positively plant growths as foliate fertilization without significantly contributing to the soil nutrient pool, or compensating nutrient losses by soil leaching and accelerated erosion. The correction of the masking effect of atmospheric fertilization can be done by considering the quantum of biomass improvement in intact vegetation area, using the method proposed in Vlek et al. (2010) and Le et al. (2012b). However the result must be evaluated by comparing the spatial corrected NDVI trend pattern with independent indicators, such as ground-measured NPP or soil erosion (e.g. Le et al., 2012b).

THE CONCEPTUAL FRAMEWORK

The conceptual framework (Figure 1) categorizes the causes of land degradation into proximate and underlying, which interact with each other to result in different levels of land degradation. Proximate causes of land degradation are those that have a direct effect on the terrestrial ecosystem. The proximate causes are further divided into biophysical proximate causes (natural) and unsustainable land management practices (anthropogenic). The underlying causes of land degradation are those that indirectly affect the proximate causes of land degradation, such as institutional, socio-economic and policy factors. For example, poverty could lead to the failure of land users to invest in sustainable land management practices leading to land degradation (Way 2006, Cleaver and Schreiber 1994, Scherr 2000). Understanding of causes of land degradation and of their interactions is essential for identifying relevant actions for addressing land degradation.

Therefore, as we will see further, the first step in the empirical ELD research involves the analysis of both proximate and underlying causes of land degradation. The analytical methods used for this purpose are described in the empirical section under *Analysis of causes of land degradation* in page 9.

Inaction against land degradation would lead to continuation, even acceleration, of land degradation and of its associated costs. However, besides its benefits, action against land degradation also involves costs - the costs of specific measures and economy-wide indirect effects - that is, opportunity costs, involving resources devoted for these actions which cannot be used elsewhere. The ultimate goal of the ELD conceptual framework is to compare the costs and benefits of action against land degradation versus the costs of inaction.

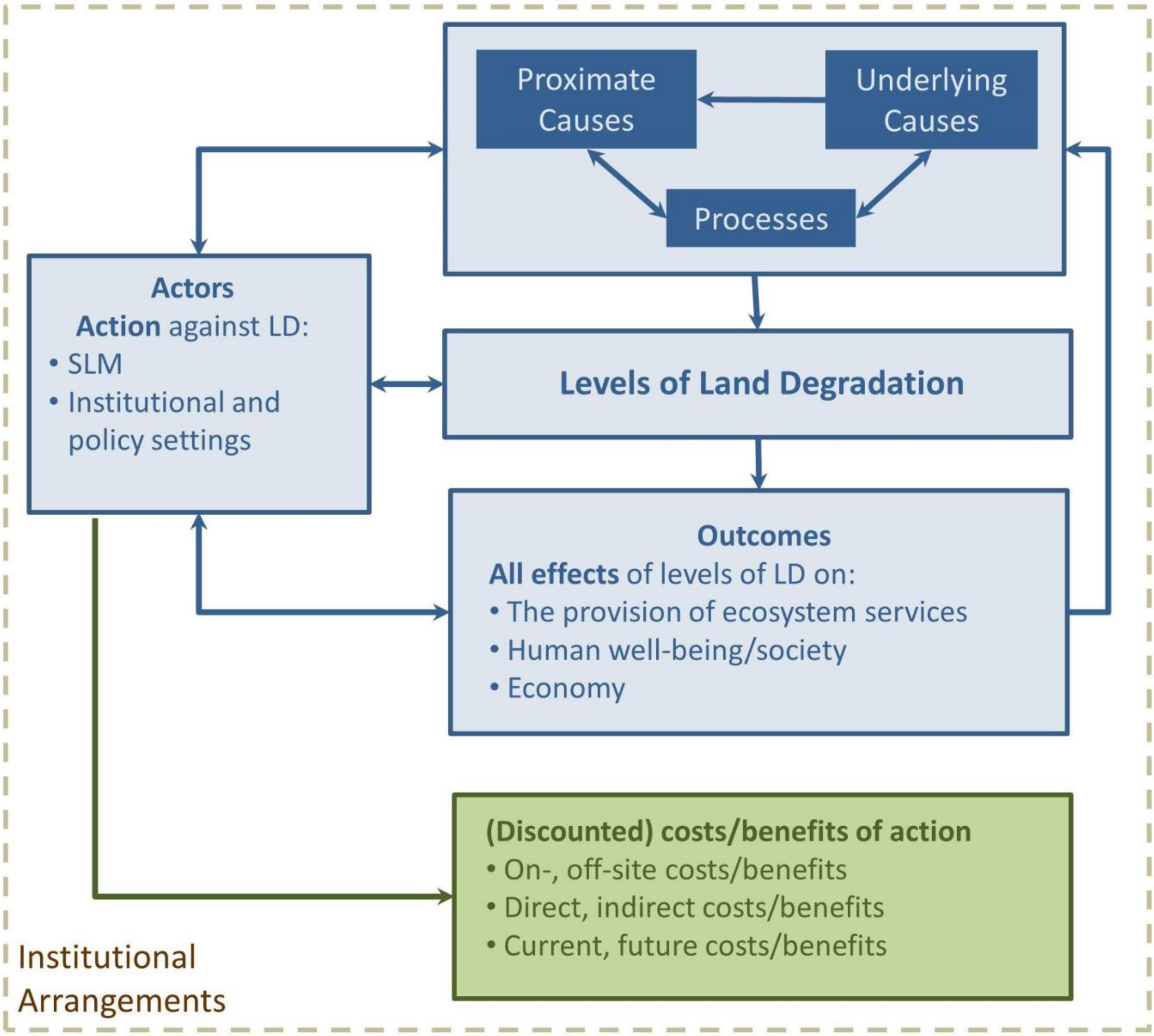

Figure 1. The Conceptual Framework of ELD Assessment
Source: adapted from Nkonya et al. (2011)

The level of land degradation determines its outcomes or effects - whether on-site or offsite - on the provision of ecosystem services and the benefits humans derive from those services. Other methods are also used to measure the on-site and off-site flow and stock of ecosystems services. Of particular importance is the life cycle analysis (LCA), which assesses the environmental impacts of a product during its life cycle (Rebitzer et al 2004). In what is known as the environmental impact of products from its cradle to its grave, impact categories of a product and the corresponding indicators and model(s) are identified (Reap et al 2008). The impact results are then grouped into different categories (Ibid). Despite its popularity of LCA and codification in the International Standardization Organization, LCA has a number of weaknesses (ibid.). There is no consensus on types of stressors, impacts, the models to use and corresponding indicators under consideration (ibid). Like TEV, double counting remains a major problem of LCA (ibid). Due to these problems and given that TEV methods also trace the on-site and off-site impacts of the ecosystem services, this study will use the TEV approach.

Many of the services provided by ecosystems are not traded in markets, so the different actors do not pay for negative or positive effects on those ecosystems. The value of such externalities may not be considered in the farmer's land use decision, which leads to an undervaluation of land and its provision of ecosystem services. The ecosystem services should be considered as capital assets, or natural capital (Daily et al. 2011, Barbier 2011c). This natural capital should be properly valuated and managed as any other form of capital assets (Daily et al. 2000). The failure to capture these values for land ecosystems could lead to undervaluing the impact of higher rates of land degradation. To adequately account for ecosystem services in decision making, the economic values of those services have to be determined. There exist various methods to evaluate ecosystem services (Barbier 2010, 2011a, 2011b, Nkonya et al. 2011)., However, attributing economic values to ecosystem services is challenging, due to many unknowns and actual measurement constraints. The valuation of the natural capital, therefore, should follow three stages (Daily et al. 2000): i) evaluation of alternative options, for example, degrading soil ecosystem services vs. their sustainable management, ii) measurement and identification of costs and benefits for each alternative, and iii) comparison of costs and benefits of each of the alternatives including their long-term effects (ibid.). However, identifying and aggregating individual preferences and attached values to ecosystem services, including over time, for each alternative option, is not a straightforward task (ibid.) As economic values are linked to the number of (human) beneficiaries and the socioeconomic context, these services depend on local or regional conditions. This dependence contributes to the variability of the values (TEEB 2010).

The green square box in Figure 1 deals with the economic analysis to be carried out, and the green arrow shows the flow of information that is necessary to perform the different elements of the global economic analysis. Ideally, all indirect and off-site effects should be accounted for in the economic analysis to ensure that the assessment is from society's point of view and includes all existing externalities, in addition to the private costs that are usually considered when individuals decide on land use. This assessment has to be conducted at the margin, which means that costs of small changes in the level of land degradation, which may accumulate over time, have to be identified. Bringing together the different cost and value types to fully assess total costs and benefits over time and their interactions can be done within the framework of cost–benefit analysis and mathematical modeling. In doing this, care should be taken in the choice of the discount rates because the size of the discount rate, as well as the length of the considered time horizon, can radically change the results. Discount rates relate to people's time preferences, with higher discount rates indicating a strong time preference and attaching a higher value to each unit of the natural resource that is consumed now rather than in the future.

Institutional arrangements, or the "rules of the game" that determine whether actors choose to act against land degradation and whether the level or type of action undertaken will effectively reduce or halt land degradation, are represented as dotted lines encapsulating the different elements of the conceptual framework. It is crucial to identify and understand these institutional arrangements in order to devise sustainable and efficient policies to combat land degradation. For example, if farmers over-irrigate, leading to salinization of the land, it must be understood why they do so. As an illustration, it may be that institutional arrangements, also referred to as distorting incentive structures, make it economically profitable for farmers to produce as much crops as possible. Missing or very low prices of irrigation water in irrigation schemes may act as such an incentive in a misleading institutional setup (Rosegrant et al. 1995).

Finally, it is also essential for the analysis to identify all the important actors of land degradation, such as land users, landowners, governmental authorities, industries, and consumers, as well as identify how institutions and policies influence those actors. Transaction costs and collective versus market and state actions are to be considered.

THE ANALYTICAL FRAMEWORK

The analytical framework adopted by this ELD assessment consists of three mutually reinforcing categories (Table 2):

1. **Core ELD research methods:** standard research methods to be applied in all case studies to fulfill the minimum methodological requirements for globally comparable and rigorous ELD assessment.
2. **Desirable ELD approaches**: methods that do not need to be exactly similar and standard in all case study countries, but are highly desirable to be applied, in locally appropriate forms, seeking to address the key challenges specific in each context. They will seek to complement, cross-validate and triangulate, in general, test the robustness of the results obtained from the core research by using alternative methods or datasets and/or provide more detailed analysis of some specific aspects and impacts of land degradation and sustainable land management.
3. **Sophisticated ELD methods** for expanding the research frontiers in ELD research. They aim to build and expand on the cutting-edge of interdisciplinary land degradation research.

Table 2. Examples of three categories of ELD research

Core	Desirable	Sophisticated
Descriptive and econometric analysis of causes of land degradation	Detailed analyses of poverty-land degradation, food security-land degradation interactions	Game theoretic and experimental economics approaches for assessing household risk attitudes, etc
	Causes of SLM adoption	Field assessments of the value of ecosystem services
Bio-economic modeling of action vs inaction against land degradation, including simulation of selected institutional and policy options for addressing land degradation	Triangulation of different crop modeling approaches within the bio-economic modeling	The use of mobile communications and ICT tools for identification /ground-truthing of land degradation
	Inter-sectoral effects of land degradation beyond agriculture within general equilibrium analyses	Integrated application of high resolution remote sensing and GIS together with economic analysis using spatial econometric methods
	Other options relevant for partners and stakeholders	Other options relevant for partners and stakeholders

Source: the authors

The core methods column consistent of two elements: 1) descriptive and econometric analysis of causes of land degradation, and 2) bio-economic modeling of action vs inaction against land degradation, including simulation of selected institutional and policy options for addressing land degradation. These two core methods correspond to the elements of the conceptual framework (i.e., identification of proximate/underlying causes of land degradation, and assessment of costs action vs. inaction of land degradation). The specific empirical methods for these two research activities are described in the *Core* *empirical methods* section that follows. These core methods are meant to be common for all case study countries and are minimum necessary requirement for conducting an ELD case study.

However, in addition to them we include desirable, i.e. those research topics which of very high interest but may not be implemented uniformly in all countries, and are optional elements of ELD research subject to time and budget constraints; and sophisticated, i.e. cutting edge economic research activities highly needed for pushing the frontiers of economics research in this area, but which are, similarly to desirable category, not obligatory to be conducted in all case study countries. We do not provide the descriptions of specific analytical methods for methods in desirable and sophisticated categories since the list given is indicative and optional. Each case study can have different desirable or sophisticated research activities, even not included here in the table. The concepts and methods for these non-core research elements, hence, will be elaborated separately on case by case basis.

The next section on Core empirical methods provides with the empirical analytical methods for the two research activities to be conducted under the core category.

CORE EMPIRICAL METHODS

The core analytical approaches consist of two mutually complementary lines of research, which tackle two different aspects of the research agenda described in the conceptual framework (Figure 1). This first line of research is based on descriptive and econometric analysis of causes of land degradation. Here, we seek to identify the key underlying and proximate causes of land degradation. This analysis will help to identify strategies for taking action against land degradation. However, action or non-action against land degradation will depend on its costs and benefits of taking action. This justifies and links the first part to the second part of analysis, whereas the second line of research looks specifically into the costs of land degradation and net benefits from SLM through bio-economic modeling. The research results on key causes of land degradation in each case study context also inform the choice of institutional and policy scenarios to be modeled under the bio-economic modeling.

Analysis of Causes of Land Degradation

As one can see from Table 3, the causes of land degradation are numerous, interrelated and complex. Quite often, the same causal factor could lead to diverging consequences in different contexts because of its varying interactions with other proximate and underlying causes of land degradation. The results imply that targeting one underlying factor is not, in itself, sufficient to address land degradation. Rather, a number of underlying and proximate factors need to be taken into account when designing policies to prevent or mitigate land degradation. For our model specification, it is essential not to look for only into individual causes of land degradation, but rather identify the effects of various combinations and interactions of underlying and proximate causes of land degradation in a robust manner, with appropriate handling of potential issues related to endogeneity, multicollinearity, omitted variable bias and other statistical challenges.

Table 3. Proximate and underlying causes related to land degradation (selective)

Factors	Type	Examples of causality	References
Topography	proximate and natural	Steep slopes are vulnerable to severe water-induced soil erosion	Wischemeier (1976) Voortman et al. (2000)
Land cover	proximate and natural/anthropogenic	Conversion of rangelands to irrigated farming with resulting soil salinity. Deforestation.	Gao and Liu (2010) Lu et al. (2007)
Climate	proximate and natural	Dry, hot areas are prone to naturally occurring wildfires, which, in turn, lead to soil erosion. Strong rainstorms lead to flooding and erosion. Low and infrequent rainfall and erratic and erosive rainfall (monsoon areas) lead to erosion and salinization.	Safriel and Adeel (2005) Barrow (1991)
Soil erodibility	proximate and natural	Some soils, for example those with high silt content, could be naturally more prone to erosion.	Bonilla and Johnson (2012)
Pest and diseases	proximate and natural	Pests and diseases lead to loss of biodiversity, loss of crop and livestock productivity, and other forms of land degradation	Sternberg (2008)
Unsustainable Land Management	proximate and anthropogenic	Land clearing, overgrazing, cultivation on steep slopes, bush burning, pollution of land and water sources, and soil nutrient mining are among the major causes of land degradation	Nkonya et al (2011) Nkonya et al (2008) Pender and Kerr (1998)
Infrastructure Development	proximate and anthropogenic	Transport and earthmoving techniques, like trucks and tractors, as well as new processing and storage technologies, could lead to increased production and foster land degradation if not properly planned	Geist and Lambin (2004)
Population Density	underlying	No definite answer. Population density leads to land improvement Population density leads to land degradation	 Bai et al. (2008); Tiffen et al. (1994), Boserup (1965) Grepperud (1996)
Market access	underlying	No definite answer. Land users in areas with good market access have more incentives to invest in good land management. High market access raises opportunity cost of labor, making households less likely to adopt labor-intensive sustainable land management practices.	 Pender et al. (2006) Scherr and Hazell (1994)
Land tenure	underlying	No definite answer. Insecure land tenure can lead to the adoption of unsustainable land management practices. Insecure land rights do not deter farmers from making investments in sustainable land management.	 Kabubo-Mariara (2007) Besley (1995), Brasselle et al. (2002)
Poverty	underlying	No definite answer. There is a vicious cycle between poverty and land degradation. Poverty leads to land degradation	 Way (2006); Cleaver and Schreiber (1994);

Factors	Type	Examples of causality	References
		and land degradation leads to poverty. The poor heavily depend on the land, and thus, have a strong incentive to invest their limited capital into preventing or mitigating land degradation if market conditions allow them to allocate their resources efficiently.	Scherr (2000) de Janvry et al. (1991) Nkonya et al. (2008)
Access to agricultural extension services	underlying	No definite answer. Access to agricultural extension services enhances the adoption of land management practices Depending on the capacity and orientation of the extension providers, access to extension services could also lead to land-degrading practices.	Clay et al. (1996) Paudel and Thapa (2004) Benin et al. (2007), Nkonya et al. (2010)
Decentralization	underlying	Strong local institutions with a capacity for land management are likely to enact bylaws and other regulations that could enhance sustainable land management practices	FAO (2011)
International policies	underlying	International policies through the United Nations and other organizations have influenced policy formulation and land management	Sanwal (2004)
Non-farm employment	underlying	Alternative livelihoods could also allow farmers to rest their lands or to use nonfarm income to invest in land improvement.	Nkonya et al. (2008)

Source: von Braun et al. (2013).

At the start of the empirical work, an exploratory analysis will be conducted for better understanding the characteristics and trends in land degradation, the interaction of proximate and underlying causes of land degradation and other relevant socio-economic data. This exploratory analysis will also be used for refining the hypotheses about the causes of land degradation, which will be later tested using the in-depth data in each case study country. The exploratory analysis will be done using simple descriptive tools, while the results will be illustrated using maps, figures and tables. For example, correlation between poverty, government effectiveness, land tenure, environmental policies and other key causes of land degradation will be overlaid with a change in NDVI or other relevant land degradation indicators. This will form useful and simple patterns to be used to enrich the econometric results. For example, data on land tenure will be overlaid with change in NDVI to show areas where NDVI decreased (possible land degradation) or increased (possible land improvement) while such areas had secure land tenure or insecure land tenure.

Therefore, the proximate and underlying causes of land degradation will be analyzed at three levels.

(i) *Global at pixel level*. Like in Nkonya et al (2011), a pixel-level estimation of causes of land degradation will be made. However, this study will improve on the Nkonya et al (2011) by using more recent data and controlling for more causes of land degradation (see Table 7). Moreover, NDVI values used in this analysis will be corrected for the effects of fertilization that has been shown dissimulate land degradation (Vlek et al. 2010). A structural model will be estimated – and as far as availability of instrumental variables (IV) permits, a two-stage least square (2SLS) model will be applied to address potential endogeneity biases.

(ii) District level in case study countries. Contingent on data availability in the case study countries, a panel data at district level will be formed to analyze the land degradation causes at district level. Available data on severity of poverty and household surveys with a large number of variables are shown in **Error! Reference source not found.**. Since most of these data are cross-sectional, they will be aggregated at district level to form a panel.

(iii) Household level analysis in the case study countries with panel (or cross-sectional, if panel is not available) household data. Using land use change, or households' reporting of their plot level land quality, or factual measurements of land quality at the household plots, or very high resolution NDVI images, as available, as an indicator for land degradation (Table 7).

The choice of variables for model specification is based on theoretical grounds and previous research, which has been described in detail in Nkonya et al (2011) and von Braun et al (2013). Additionally they follow established literature on causes of land degradation (Meyfroidt et al (2010); Lambin 2001); Lambin and Geist 2006, Table 3).

Following Meyfroidt et al (2010); Lambin (2001); Lambin and Geist (2006) and Nkonya et al (2011), the structural first difference model estimating causes of land degradation or land improvement at global, regional/district and household levels**,** using annualized data is:

$$\Delta \text{ NDVI} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1}\Delta \boldsymbol{x_1} + \boldsymbol{\beta_2}\Delta \boldsymbol{x_2} + \boldsymbol{\beta_3}\Delta \boldsymbol{x_3} + \boldsymbol{\beta_4}\Delta \boldsymbol{x_4} + \boldsymbol{\beta_5}\Delta \boldsymbol{z_i} + \boldsymbol{\varepsilon_i} \quad \textbf{(1)}$$

where,

$\mathbf{x_1}$ = a vector of biophysical causes of land degradation (e.g. climate conditions, topography, soil constraints);

$\mathbf{x_2}$ = a vector of policy-related, institutional, demographic and socio-economic causes of land degradation (e.g. population density and growth rate, urban growth, GDP per capita, agricultural intensification and growth, national, international policies directly affecting land management, government effectiveness, land tenure, etc);

$\mathbf{x_3}$ = a vector of variables representing access to rural services (e.g. links to extension services, road proximity or density, access to information, assess to rural credits);

$\mathbf{x_4}$ = vector of variables representing rural household level capital endowment, level of education, poverty level, physical capital, social capital;

$\mathbf{z_i}$ = vector of fixed effect variables, including administrative divisions (region, NDVI prior to the baseline period, etc).

Alternatively, this model could be estimated using fixed effects approach instead of the first difference approach. The choice between first difference and fixed effects estimations usually depends on the characteristics of the panel data and specifically those of the error term. We expect the error terms to follow random walk, requiring first difference estimation rather than being serially uncorrelated when fixed effects is better. However, the ultimate choice between first difference and fixed effects should be made based on the characteristics of the actual data used.

Various appropriate interactions and nonlinear relationships among specific variables will also be tested following theoretical expectations. The results of this model will also be triangulated whenever possible using alternative measures of land degradation as dependent variable (such as actual soil quality measurements, etc).

The use of NDVI or other satellite-derived measures as proxies of land degradation may occasionally lead to less accurate results as NDVI or other satellite-derived indicators may not be fully collinear with land degradation processes on the ground. For example, NDVI cannot easily differentiate between composition changes in vegetation, hence can lead to misleading conclusions when secondary salinization leads to abandonment of previously agricultural areas and replacement of agricultural crops by halophytic weeds. To minimize such inaccuracies, ground-truthing of satellite-derived data will be conducted in close cooperation with local partners, whenever appropriate through the use of innovative crowd-sourcing approaches involving the use of mobile communications. More specifically, two complementary options for ground-truthing the satellite-based information will be used. Firstly, sub-national ground-truthing studies will be conducted in some case study countries to assess land degradation using local-specific data to triangulate the results with the global satellite-based analysis. This work will also provide with much higher resolution mapping of land degradation than available from the global-level exercise. Secondly, efforts will be directed at catalyzing crowdsourcing platforms based on mobile networks for getting direct user observations from the ground for ground-truthing the satellite data. Specifically, land users will be asked to give the land degradation status of their plots each with corresponding GPS coordinates. A mobile phone application on land degradation will be developed using the freely available web technologies (HTML and JavaScript). Crowd-sourcing of information from the population requires coding of data for uniformity in reporting. Data can then be sent to either a database in a server or as email attachment (done automatically as programmed).

However, NDVI pixels could be too big to make any meaningful conclusions at the household level. To address this problem, the above equation, which is more suited to global and district level analyses, will be modified taking alternative household-level indicators of land quality as the dependent variable, such as land use change, or households' reporting of their plot level land quality, or factual measurements of land quality at the household plots, or very high resolution NDVI data, as available. The explanatory variables will also be at the household level (2):

$$\Delta \textbf{ Household Land Quality Indicator} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1}\Delta x_1 + \boldsymbol{\beta_2}\Delta x_2 + \boldsymbol{\beta_3}\Delta x_3 + \boldsymbol{\beta_4}\Delta x_4 + \boldsymbol{\beta_5}\Delta z_i + \boldsymbol{\varepsilon_i} \quad \textbf{(2)}$$

where,

x_1 = a vector of biophysical causes of land degradation (e.g. climate conditions, topography, soil constraints) at household plots;

x_2 = a vector of policy-related, institutional, demographic and socio-economic causes of land degradation (e.g. household income per capita, family labor availability, fertilizer/manure application rates, land tenure, etc);

x_3 = a vector of variables representing access to rural services (e.g. links to extension services, road proximity or density, access to information, assess to rural credits);

x_4 = vector of variables representing household level asset endowments, level of education, poverty level, physical capital, social capital;

z_i = vector of fixed effect variables, including administrative divisions, household fixed effects, etc

Similarly, here as well, an alternative fixed effects model will also be considered. In case of cross-sectional data, the panel estimation approach will be replaced by methods suitable for cross-sectional data. Various appropriate interactions and nonlinear relationships among specific variables will be tested following theoretical expectations.

Bio-economic modeling:
Cost and benefits of action vs. inaction against land degradation

The TEV approach is required to comprehensively capture the costs of land degradation. It consists of use and non-use values (Remoundou et al. 2009). The use value is further divided into direct and indirect use. The direct use includes marketed outputs involving priced consumption (e.g. crop production, fisheries, tourism, etc) as well as un-priced benefits such as local culture and recreation. The indirect use value consists of un-priced ecosystem functions such as water purification, carbon sequestration, etc. Non-use value is divided into bequest, altruistic and existence values, all of which represent the un-priced benefits. In between these two major categories, there is the option value, which includes both marketable outputs and ecosystem services for future direct or indirect use. It is usually challenging to measure the non-use and indirect use values as mostly they are not traded in markets. An additional challenge of measuring TEV is the potential of double-counting of benefits from ecosystems services (Barbier 2010). Following Balmford et al. (2008) and others, care will be taken to avoid double counting, by partitioning the broad but closely related benefits and process and traced their links such that they avoided double-counting (ibid).

Since we follow the broad definition of land degradation which captures the on-site and off-site effects of land management, we use social costs and benefits of land degradation. The social cost and benefit of action against land degradation and inaction is given by the net present value (NPV) for taking action against land degradation in year t for the land users planning horizon T:

$$\pi^c_{t\,t} = \frac{1}{\rho^t}\sum_{t=0}^{T}(PY^c_t + IV_t + NU_t + b^c_t - lm^c_t - c^c_t - \tau^c_t) \quad \textbf{(3)}$$

Where π_t = NPV; Y^c_t= production of direct use provisioning services when using SLM practices; P= unit price of Y^c_t; IV_t = indirect use value; NU_t = on-site non-use value; b^c_t = off-site positive benefit of SLM practices ρ^t = 1+r, r = land user's discount rate; lm^c_t = cost of SLM practices; c^c_t = direct costs of production other than land management; τ^c_t = off-site costs of SLM – including use and non-use costs. The term τ^c_t implies that even SLM could produce negative off-site costs. For example, application of chemical fertilizer leads to greenhouse gas emission. One kg of nitrogen requires about 3 kg of CO_2-eqivalent (Vlek et al., 2004) because of the high energy requirement for the manufacture and transport of fertilizer.

If land user does not take action against land degradation, the corresponding NPV is given by

$$\pi^d_t = \frac{1}{\rho^t}\sum_{t=0}^{T}\left(PY^d_t + IV_t + NU_t + b^d_t - lm^d_t - c^d_t - \tau^d_t\right) \quad \textbf{(4)}$$

Where π_t^d = NPV when land user uses land degrading practices. All other variables are as defined in above but with superscript d indicating land degrading practices.

The benefit of taking action against land degradation is given by $BA = \pi_t^c - \pi_t^d$.

The difference $\pi_t^c - \pi_t^d$ plays an important role in land users' decision making during their planning horizon T. Table 4 summarizes the actions of land users when returns to SLM are smaller, greater or equal to the corresponding returns to SLM. If the returns to land management for the SLM are smaller than the corresponding returns for land degrading practices, the land user is likely to use land degrading practices.

Table 4. Action vs inaction decisions at different levels

$\pi_t^c - \pi_t^d$	Logical action/inaction
> 0	Take action against LD
< 0	Don't take action. Alternatively provide incentives to take action against land degradation (e.g. PES*)
= 0	Indifferent, hence provide incentives to take action against land degradation (e.g. PES)

NB: Taking action against land degradation include: prevention of land degradation or rehabilitation of degraded lands
*Payment for Ecosystem Services. Source: the authors.

However, given that prevention of land degradation is expected to be cheaper than rehabilitation of degraded lands, it is always prudent to prevent land degradation. The challenge is internalization of SLM benefits and enhancing adoption of SLM practices for low income farmers who may not have paid to adopt SLM. For example, payment for ecosystem services (PES) could be used when BA ≤ 0 (see Table 4).

The modeling is done at the level of representative farm types corresponding to major farming systems in each case study country. T will need to be set at a sufficient time period in order to adequately capture longer-term impacts of SLM, which may take some time to materialize. The modeling will implement several policy scenarios with outcomes on land degradation and farm income – as the guidance for policy making. It will also identify and indicate actions with some priority levels depending on the level of economic returns from each of them. The risks affecting the farm NPV would come from variability in crop/livestock productivity which depends on a host of controlled (farmers' land management decisions) or uncontrolled (weather realizations or irrigation water availability) factors. The risk prospects in the model are included through farmers' subjective probabilities and risk preferences, following the relative risk aversion coefficients approach (Anderson and Dillon 1992).

The analytical work described above will be conducted together with national researchers and practitioners in order to foster a bottom-up approach that will increase the capacity of local institutions to manage lands and to operate on a long-term basis. Moreover, the policy scenarios and recommendations, also developed in close interaction with national researchers, practitioners and farmers, will be articulated in order to promote sustainable land management by promoting the link between bottom-up and top-down approaches, and energizing horizontal and vertical linkages (Figure 2).

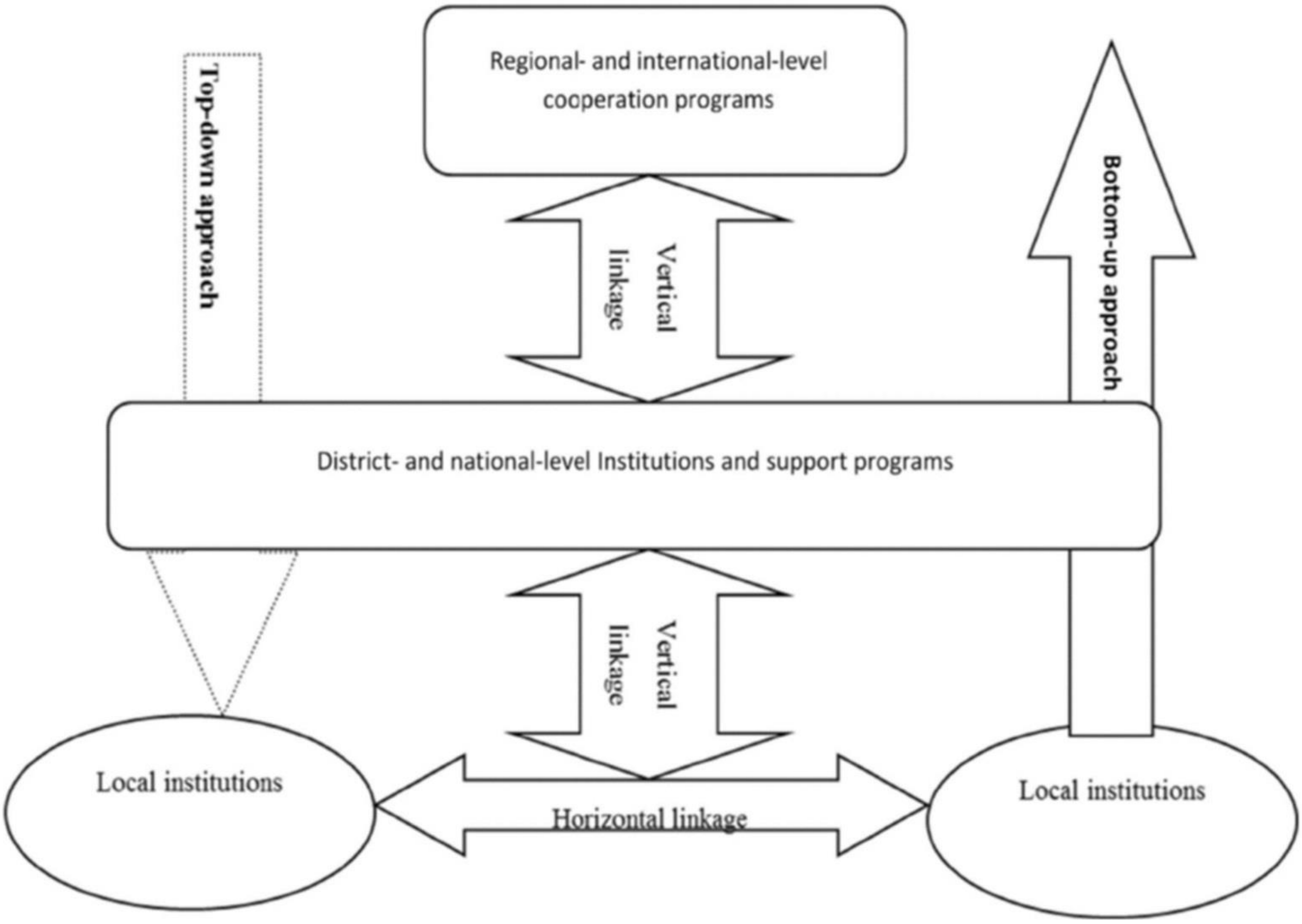

Figure 2. Bottom-up and top-down approaches for SLM
Source: Nkonya et al. (2011)

NON-CORE RESEARCH ACTIVITIES

In addition to the above core research program, several highly desirable research questions will be tackled. The specifics of these research activities and their focuses may change depending on case study country priorities. For example, the ELD core research agenda will be additionally enriched through more detailed research into the **poverty-land degradation, food security-land degradation interactions** – to better estimate the impact of land degradation on the livelihoods and food security of poor households with the aim to identify SLM measures and policies that could also decrease poverty rates and enhance food security. Furthermore, studies may be conducted to identify the benefits from the **collective action** or the **risk attitudes** of agricultural households in terms of adopting sustainable land management practices through use of **economic experiments**, where key factors shaping collective action, risk attitudes and household SLM behavior will be identified. Whenever household-level data on SLM adoption is available, they will be used, within multinomial choice model frameworks, along with a set of corresponding household-specific socio-economic, demographic, farm production, institutional and other variables, in order to identify key factors leading or constraining the adoption of SLM practices. We do not provide the descriptions of specific analytical methods for non-core research activities here in this paper since the list given is indicative and optional. Each case study country can have different non-core research activities, even not indicated here. Therefore, the concepts and methods for these non-core research activities will be elaborated separately on case by case basis.

SAMPLING FRAMEWORK FOR CASE STUDIES

It has been demonstrated ealier that proximate and underlying causes of land degradation are intricately embedded in their specific local contexts (Nkonya et al., 2011, von Braun et al. 2013), and hence, only through comprehensive analysis of these local heterogeneous interactions that meaningful insights could be derived about causes and necessary actions against land degradation. On the other hand, needless to say that these insights should not be exclusively limited only to some specific local settings, but should have a global relevance. In this regard, case study methodology is the preferred choice of method when the phenomenon being studied is indistuinguishable from its context (Yin 2003) - which enables to achieve the first objective of local thoroughness. The second objective of global relevance is achieved by designing a rigorous sampling framework with theoretically sound case study selection strategy.

Extrapolation of case study findings beyond these case studies themselves is possible only when the case study design has been based on theoretical grounds: where specific research questions are asked to test the validity of rival explanations of cause-and-effect relationships in land degradation (Table 3). Carefully selected multiple case studies are the means to provide a more convincing test of a theory and specify conditions under which different, perhaps even opposing, theories could be valid (de Vaus, 2001). Moreover, the external validity of a case study depends on its capacity for theoretical generalization, rather than statistical generalization which is conducted through probability-based random sampling techniques. In that sense, case studies are like experiments with replications: if the theoretical insights gained from case studies conducted in multiple settings coincide, then the potential of external validity of these results is higher. To achieve such external validity, case studies are selected not statistically, but “strategically” (ibid.), which necessitates selecting those cases which will enable to rigorously test the causal relationships in different contexts (ibid.). Moreover, random probability based selection of countries is also practically infeasibale within realistic time and budget constraints. Finally, it is essential that the core research methodologies and protocols in each of the case studies should be similar for ensuring comparibility of their results.

For conducting this global economic analysis of land degradation, case study countries have been carefully selected based on purposive sampling framework and maximum variation approach, where it was sought to comprehensively capture a wide spectrum of heterogeneous contexts of land degradation in order to test rival cause-and-effect hypotheses about land degradation. Thus, the main objective in the sampling was to ensure the external validity and global relevance of the selected case study countries for a big heterogeneity of land degradation, institutional and socio-economic situations around the world.

The sampling strategy consisted of three steps.

First, earlier analyses of causes of land degradation have identified such key socio-economic and institutional underlying factors of land degradation as per capita GDP, population density, government effectiveness and agricultural intensification (Nkonya et al. 2011). Based on these characteristics, the countries of the world have been clusterd using K-means clustering tecnique into seven clusters with more homogenous within-cluster characteristics. The decision on the optimal number of clusters was guided both by the results of the formal statistical Calinsky-Harabasz stopping rule (Calinsky and Harabasz, 1974) [1] , and graphical and numerical exploratory analysis of the data.

Second, the selected clusters were formally validated against several key socio-economic and biophysical variables, which were not part of the inital clustering, such as long-term changes in remotely-sensed NDVI values (Tucker et al. 2004), which can be used as a potential proxy for land degradation, share of rural population in the total, share of agriculture in GDP, average cereal yields per hectare. The identfied clusters showed significant differences for each of these variables, thus providing a strong evidence for the validity of the clustering approach employed (Table 5. Figure 3).

Third, once the countries have been put through these selection filters to ensure their representativeness of global heterogeneity in terms of socio-economic, institutional and land degradation characteristcis, countries were selected from each cluster for in-depth case studies, based on such additional ciriteria as i) regional representativeness, ii) the selected countries have collected or are collecting the data required for the ELD assessment.

This selection of countries is highly and sufficiently heterogeneous in terms of both biophysical, socio-economic and institutional characteristics to enable rigourous ground-level testing of various causal hypotheses about land degradation, and for specifying which causal relationships could be prevailing under each of these different interactions of factors (see Section on *Causes of Land Degradation* above). The representativeness of the case study countries is also demonstrated by their good coverage of the world biomes (Figure 4) and farming systems typologies (Annex 1). Moreover, these globally representative case studies also allow for achieving our objective of providing national and global-level estimates of costs of land degradation and net benefits of taking action against it through SLM investments and policies (see section on *Cost and benefits of action vs inaction against land degradation* below).

In-depth case studies are planned to be conducted in 11 of these case study countries (hihglighted in yellow, Table 6), while second-tier case studies will be conducted in the remaining nine countries (highlighted in blue, Table 6), even though in less intensive level and exclusively based on already available data, namely, spatial GIS data, existing household surveys, and secondary statistics at district level.

Given higher levels of development challenges and opportunities posed by land degradation impacts, Cluster 1 countries are given higher weight in this particular selection. Naturally, the more is the number of case study countries, the higher is the accuracy of extrapolation – so depending on time and budgetary constraints, efforts will be made to include as many of these additonal countries in the in-depth analysis, but also, to further increase the number of case study countries. What is important, this framework can provide a consistent conceptual basis for adding more case studies from around the world for the comparable ELD assessment under other ongoing or future ELD-releated research activities, with the important pre-condition that the same core methods will be applied.

[1] Milligan and Cooper (1985) conclude, using a Monte Carlo simulation, that Calinsky-Harabasz stopping rule provides the best results among the 30 stopping rules they have compared.

Table 5. Clustering and validation results

Clusters	GDP per capita	Government effectiveness	Population density	Agricultural Intensification	Maximum changes in NDVI values between the baseline (1982-84) and endline (2003-06)*	Cereal yields	Share of Agriculture in GDP	Share of Rural Population in Total
1	lower	lower	Higher	lower	Highest dispersion, both biggest decreases and increases	lower	higher	higher
2	mid	mid	Higher	higher	smaller decreases	mid	mid	higher
3	mid	mid	Higher	mid	smaller decreases	mid	mid	mid
4	mid	mid	Lower	mid	larger decreases	mid	mid	lower
5	mid	mid	Lower	lower	smaller decreases	lower	mid	mid
6	higher	higher	Mid	higher	larger decreases	mid	mid	lower
7	higher	higher	Higher	higher	smaller decreases	higher	lower	lower

Source: the authors.

Notes:
i) For easy reading of color patterns: cells expected to show strong negative association with land degradation, or being strongly negatively affected by land degradation are colored in red. Similarly, medium and lower levels are depicted with brown and green colors, respectively. * The NDVI time-series comes from GIMMS dataset, which is driven from NOAA AVHRR satellite data (http://glcf.umd.edu/). The NDVI changes here-calculated have not been corrected for the effects of inter-annual rainfall variation, atmospheric fertilization and human application of mineral fertilizer. Appropriate analysis of inter-annual NDVI trend with the consideration of these effects (e.g. Vlek, Tamene and Le, 2010) will be done as a part of this ELD research.

Table 6a. Tentative case study countries by cluster (in-depth case studies highlighted in yellow)

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Ethiopia	China	Turkey	Argentina	Bhutan	Colombia	Germany
Kenya	India	Uzbekistan	Peru	Russia		USA
Nigeria	Egypt	Morocco				
Senegal						
Niger						
Tanzania						
Malawi						

Source: the authors.

Table 6b. Tentative case study countries by region (in-depth case studies highlighted in yellow)

Sub-Saharan Africa	North Africa and Near East	Asia	Latin America	Europe and North America
Ethiopia	Turkey	Bhutan	Argentina	Germany
Kenya	Egypt	China	Peru	USA
Niger	Morocco	India	Colombia	
Nigeria		Uzbekistan		
Senegal				
Tanzania				
Malawi				

Source: the authors.

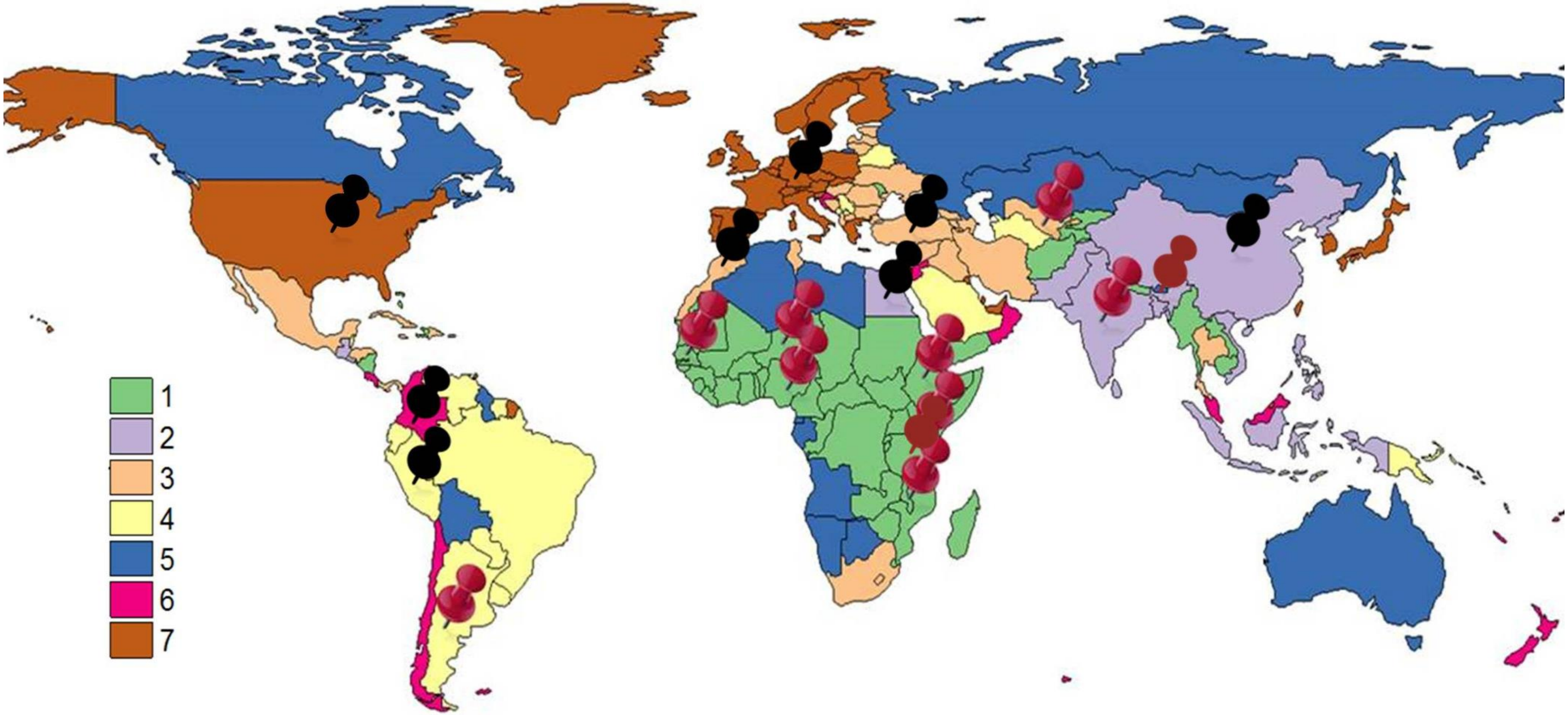

Figure 3. Global Map showing clusters and case study countries (red pins showing countries for in-depth analysis, black pins showing second-tier case studies). Source: the authors.

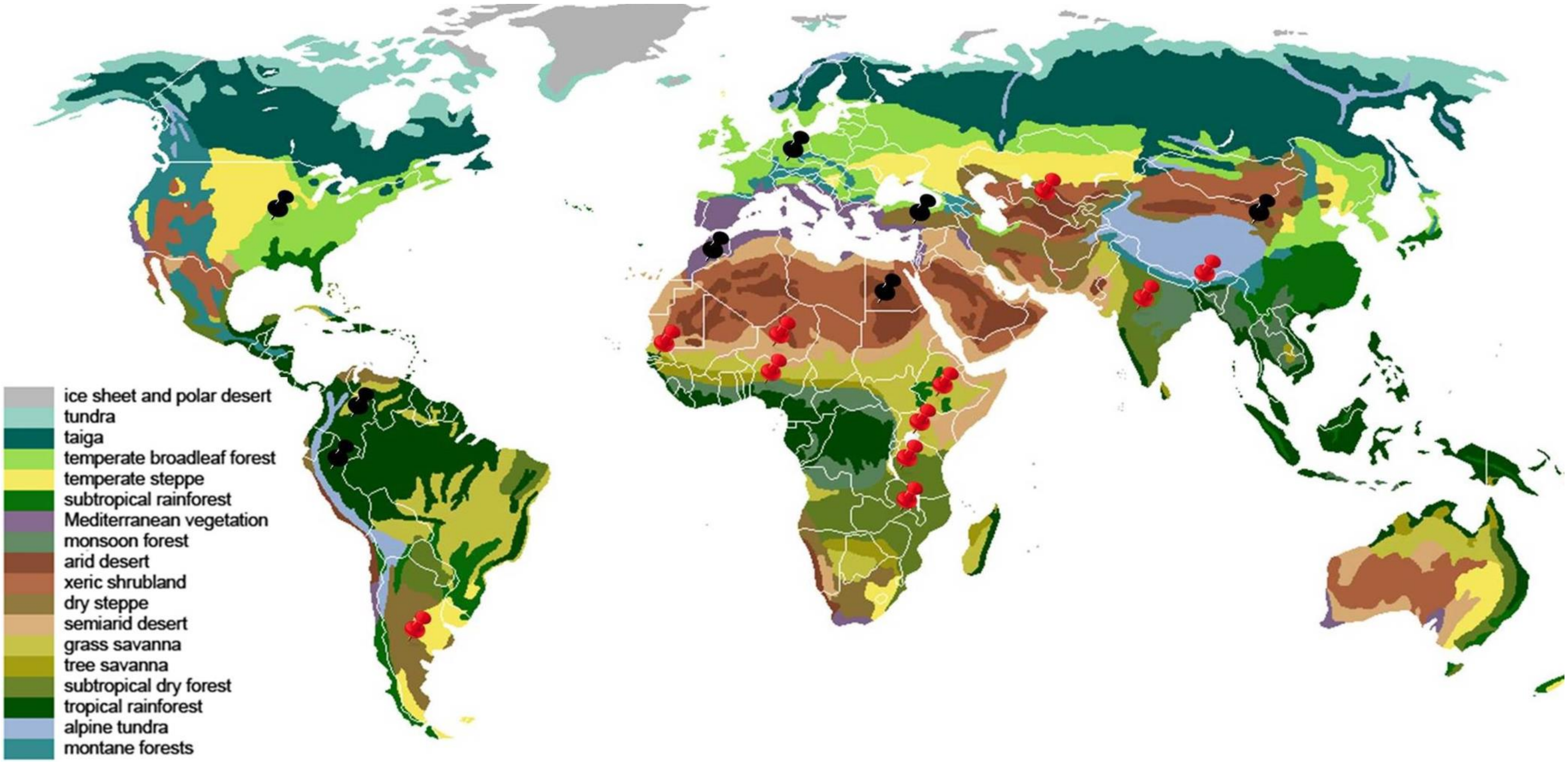

Figure 4. Global Map showing the correspondence of case study countries to major global biomes (red pins showing countries for in-depth analysis, black pins showing second-tier case studies).

Source: modified from Wikipedia Commons, from http://commons.wikimedia.org/wiki/File:Vegetation-no-legend.PNG, accessed on 08 October 2013.

Following this sampling framework, and using the European Joint Research Center (JRC) guidelines (Toth et al. 2012), the data collected from the case study countries will be interpolated across the corresponding farming systems within the same cluster or the same region. The global map of farming system zones (Dixon et al. 2001) – defined as farm systems with similar resource and enterprise patterns, household livelihoods and constraints, and which are likely to have similar development pathways – will be used. This is appropriate because the global farming system zones show strata of social-ecological factors that are consistent with potential causes of land degradation as summarized in von Braun et al. (2013). Hence interpolation of case studies' results, i.e. of **SLM actions required for addressing land degradation**, along farming systems will be appropriate. No interpolation will be made across regions. For example, no data from Sub-Saharan Africa will be interpolated to Latin America or Asia. This is because the interpolation within a region increases the accuracy of results as there are unobservable characteristics that could play an important role in causing land degradation. Interpolating within a region minimizes such omitted variable effects.

DATA

Data sources for analyzing the causes of land degradation

Data for determining the causes of land degradation will be obtained from sources shown in Tables 7 and 8, as well as other sources. Tables 7 and 8 show the rich data sets currently available. Efforts will be made to obtain better data from the large number of collaborators of this study and from other sources. Given that these data will be at different resolutions and from different sources, method of harmonizing their geographical representations and spatial resolution suggested by Toth et al. (2010) will be used.

A number of variables will be added in the global and regional models estimated in the Nkonya et al (2011). This will improve model estimation and reduce the misspecification bias. The new variables include global soil properties, topography; land tenure, access to information, road density, severity of poverty, and national policies – particularly environmental policies. The dependent variable: NDVI values will be corrected and calibrated to account for the effects of fertilization.

Due to rich data availability, more rigorous analysis will be done in the case study countries using household level data surveys, biophysical characteristics from satellite imagery data, national environmental data. The data from case study countries will be useful in preparing country-specific technical reports, policy briefs and other important messages.

Table 7. Data for causes of land degradation and their availability (global level analysis) (selective)

Data	Data source	Web-link/source	Availability
NDVI	GIMMs	http://glcf.umd.edu/data/gimms/	Free
Global Administrative Borders	GADM	http://www.gadm.org/	Free
Global soil properties	ISRIC-WISE FAO/IIASA	http://www.isric.org/data/data-download http://www.fao.org/nr/land/soils/harmonized-world-soil-database/soil-quality-for-crop-production/en/	Free
Africa soil information – Geo-referenced data on Land Degradation Surveillance	AFSIS	http://www.africasoils.net/	Free
Biodiversity	PBL	Netherlands environmental assessment agency	Free
Climate conditions	East Anglia climate research unit	http://www.cru.uea.ac.uk/	Free
Land management practices	Rate of fertilizer use, conservation agriculture, etc – FAO	FAOSTAT; AQUASTAT	
Topography	Yale Center for Earth Observation (YCEO) Digital elevation model FAO CCIAR-corrected SRTM	http://www.yale.edu/ceo/Documentation/dem.html http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1	Free Free
Road density		Africa road data http://infrastructureafrica.afdb.org/models/irrigation.asp	
Access to information	Mobile phone coverage	ITU	Free
Land tenure	WRI – see Figure 3 Land tenure center, University of Wisconsin	http://www.wri.org/map/status-land-tenure-and-property-rights-2005; Land Tenure center, University of Wisconsin	Free
National policies	Environmental performance index	http://epi.yale.edu/	Free
Institutions	Government effectiveness	http://www.govindicators.org	Free
Socio-economic indicators	World Development Indicators	www.worldbank.org	Free
Population density	CIESIN	http://sedac.ciesin.columbia.edu/data/collection/gpw-v3	Free

EPI is an Index comprising 25 performance indicators of environmental policies, public health and ecosystem vitality. Government effectiveness represents quality of public services, civil services, independence from political pressures, policy formulation and implementation, government commitment and credibility to such policies.

Table 8. Available household level data in the case study countries (selective)

	Poverty		Other causes of LD	
	DHS – baseline	DHS - endline	Baseline	Endline
Argentina	None			
Ethiopia	2000	2005, 2011		
Kenya	1989 1993 1998	2003, 2008-09 2010	KIHS 2005	Tegemeo Panel data: 2000-2004, 2011
India	1992-93 1998-99	2005-06		
Niger	1992, 1998	2006		
Nigeria	1990, 1999	2003 2008 2010	i. Agric. surveys, 1983-1990 ii. IFPRI/Fadama panel survey, 2007	i. Agric. surveys 2005-2010 ii. IFPRI Fadama panel survey 2011[2]
Senegal	1986 1992-93 1999,	2005 2010-11		
Tanzania	1991-92 1994 1995,	2011-2012 2010		
Uzbekistan	1996	2002		

Data for analyzing action and inaction against land degradation

***Land productivity** ($Y_t^{c,d}$):* Given that land management practices have long-term benefits and costs, time series data of land productivity associated with practices are required to compute the returns to action/inaction against land degradation. Focus of the land management will be on croplands and rangelands, which are the major land use types with severe land degradation in developing countries. To derive Y_t^c and Y_t^d for major crops (e.g. maize, wheat, and rice), we will utilize an empirical approach where extensive literature reviews along with remote sensing data and global statistics databases are employed to quantify crop yield responses to action/inaction against land degradation. For example, we will obtain current crop yields and areas at pixel levels (~10 by 10 km) from Spatial Production Allocation Model of International Food Policy Research Institute while crop yield responses to certain processes

[2] See Nkonya et al. (2012).

associated with land degradation such as soil erosion will be derived from literature. Combing this, we will be able to predict crop yield changes due to land degradation.

Ecosystem functions & services: We will quantify the impacts of land degradation on various ecosystem functions and services such as soil C sequestration rates, value of water purification, nutrient cycling, climate regulation, and so on. Soil C sequestration rates will be projected by using a process-based model (i.e. CENTURY soil organic matter model) and remote sensing databases of global soil characteristics, climatic conditions, crop productivities. Data for other ecosystem services will be obtained from past studies. A number of publications have estimated the ecosystem functions and services per hectare (e.g. Pearce 2002; Seidl and Moraes, 2000; Pearce 2001; Costanza et al 1997).[3] Care will be taken to use multiple sources for such estimates to avoid potential biases in any particular study. Moreover, when possible, field assessment will be conducted in the selected case study countries for valuing the ecosystem functions and services.

Non-use value (NU_t): like the case of indirect value data, NU_t will be obtained using past studies from areas with comparable biophysical and socio-economic characteristics. Additionally, some additional data will be collected from the case study countries to verify the NU_t data from literature. Contingent valuation and revealed preference methods will be used.

Off-site benefits and costs and other data: These data will be obtained from literature and from informal interview with key informants in the case study countries.

Table 9 summarizes the key variables to be collected under each of these two core research components.

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[3] See also http://www.ecosystemvaluation.org/dollar_based.htm

Table 9. Summary of key variables and datasets required for the core research activities

Categories	Variables	Scale (spatial/non-spatial)
Biophysical		
Climate	Mean, maximum and minimum temperatures, precipitation, solar radiation (crop modeling needs may require more)	Global (GIS) National from individual weather stations (daily and monthly)
Soils	Soil textures (clay, silt, and sand contents) and properties (organic C contents, bulk density, pH, and salinity), existing soil degradation states (soil erosion), and soil quality/constraint	National and Global (GIS)
Biomass productivity	Human-induced long-term NDVI trend	Global (GIS)
Agro-ecological	Agro-ecological zones, farming systems, length of growing period, existing land cover and land use maps, topography	National and Global GIS
Economic		
Socio-economic characteristics	Income per capita, population density, poverty rates, infant mortality rates, etc Household demographic characteristics, income (farm and non-farm) and detailed expenses, asset ownership, physical and social capital, education levels, etc	Sub-national, national and household level
Agricultural production	Crop areas and yields, input use: seeds, fertilizers, chemicals, manure, water, labor, farm machinery, fuel, others Farm characteristics, livestock ownership, output marketing, previous land use changes	Household, district and national
Prices	Output and input prices, land values when available	Sub-national and national (time series) Purchased input and marketed output prices at household level
Institutional		
Institutional	Market access, access to extension and information, access to credit, road density, night time lighting intensity series, land tenure, Government effectiveness, household risk attitudes from field experiments, membership in associations	National and household, as appropriate
SLM practices		
SLM practices	Knowledge and use of SLM practices, sources of knowledge, perceived constraints on SLM adoption	Household
SLM policies	National policies having impact on land degradation and SLM: subsidies and taxes, land use planning and production quotas, export and import tariffs, barriers and quotas, etc	National
Others		
Indirect use, non-use, and off-site values	Obtained from literature, whenever possible, own data collection and estimation	Sub-national, national and global

Conclusions and Reflections on ELD assessment

The ELD assessment is being conducted at a stage when there is an elevated interest in land investment and at a time when global efforts to achieve sustainable development have increased. The study is also being conducted at a time when spatial data availability and analytical methods have greatly improved. The proposed analytical methods and data collection will contribute greatly in informing policy makers on the best action to address land degradation. The empirical results will also serve a key role in preparing key messages targeted to policy makers, donors and other stakeholders. Given the enormous amount of data and their significant differences, only an inter-disciplinary team, working closely with all local, national and international stakeholders, can afford to collect and analyze the ELD data. The ELD team reflects this crucial condition and will work closely to produce ELD results which would be crucial in land policy formulation at national and global level.

There have been numerous but isolated attempts in the past to assess the causes and consequences of land degradation. However, the differences in concepts and methodologies did not allow for their meaningful comparison, and quite often have led to contradicting policy conclusions. Only if some basic standards are identified and adhered to, comparative assessments can be conducted between countries and useful aggregation of findings, based on these case studies, can be achieved. This is quite important for making impact on policy for investment and land use, and for getting land degradation problems out of their current obscurity. The proposed framework can provide a consistent conceptual basis for other ongoing or future ELD-releated research activities.

Certainly, causes, consequences and solutions for land degradation problems are not limited to agriculture alone. Reducing poverty, enhancing food security, promoting rural development through addressing land degradation require that the applied methodologies need to involve all the ELD relevant sectors, institutions, and policies. It is also true that one needs to start somewhere – without any doubt, agriculture is at the heart of land degradation problems, and while the other sectors need to be included too. It is also crucial to incorporate ecosystem values in assessing the costs of land degradation, in addition to direct costs. Many of the services provided by ecosystems are not traded in markets, so the different actors do not pay for negative or positive effects on those ecosystems. The value of such externalities may not be considered in the farmer's land use decision, which leads to an undervaluation of land and its provision of ecosystem services.

The ELD analytical work need to be conducted together with national researchers and practitioners in order to foster a bottom-up approach that will increase the capacity of local institutions to manage land and to operate on a long-term basis. Moreover, the policy scenarios and recommendations also need to be developed in close interaction with national researchers, practitioners and farmers, in order to promote sustainable land management by promoting the link between bottom-up and top-down approaches, and energizing horizontal and vertical linkages.

What is proposed here is a comprehensive conceptual framework for conducting the ELD assessment, concentrating on two core analytical methods demonstrating the use of methodological standards to guide other ELD case studies: 1) identify causes of land degradation, 2) bioeconomic modeling of action vs. inaction against land degradation. However, the conceptual framework represents a forward-looking agenda which can guide future research to fill all other elements of this comprehensive framework. Therefore, building national and international capacities, mobilizing bottom-up national research and action against land degradation is one of the key expectations from this ELD study.

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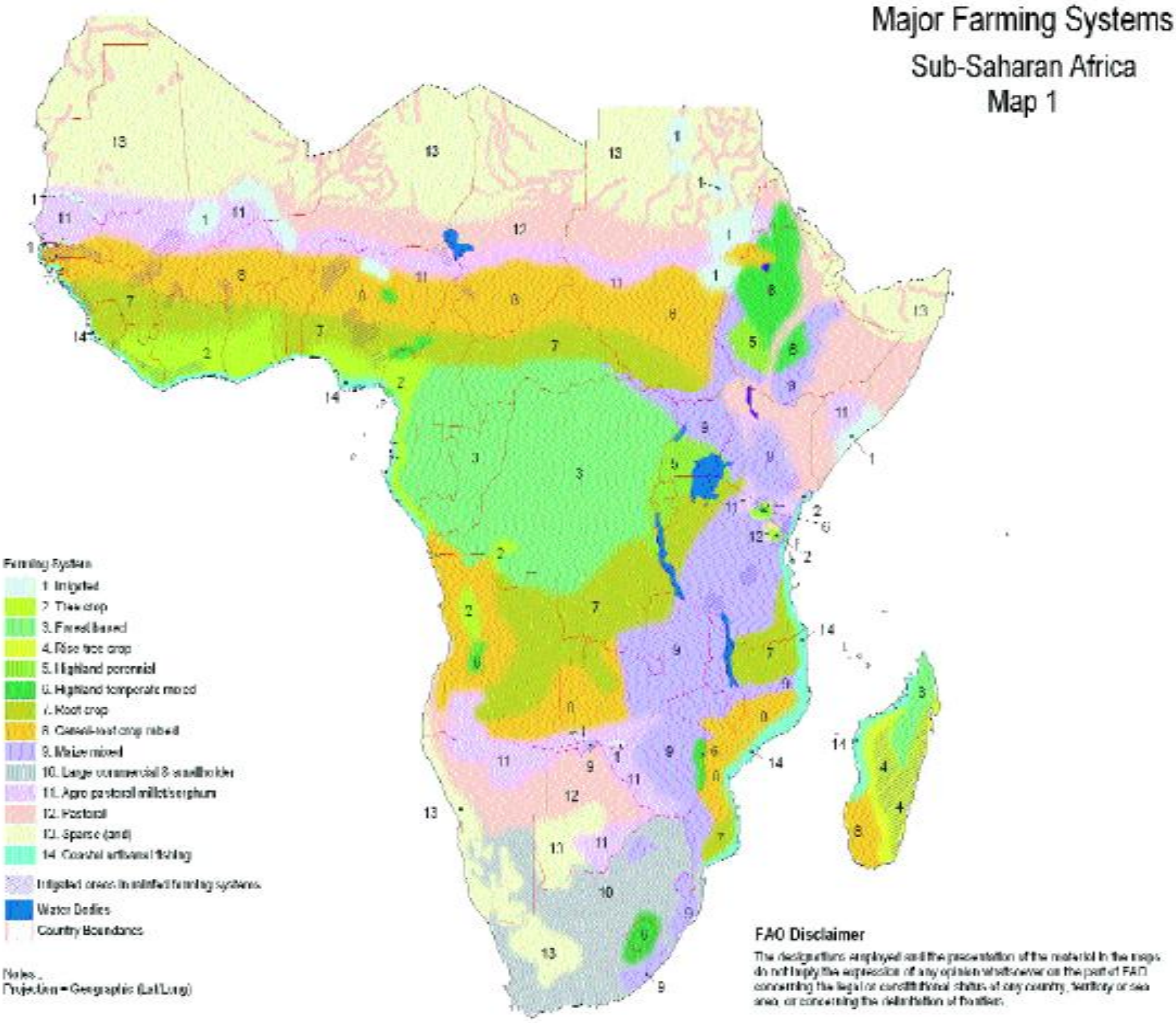
Annex 1

Sub-Saharan Africa farming systems

Farming Systems	Land Area % of region	Agric. Popn. (% of region)	Principal Livelihoods	Case study representing Farming system
Irrigated	1	2	Rice, cotton, vegetables, rainfed crops, cattle, poultry	Northern & central Nigeria
Tree Crop	3	6	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work	Central Kenya; Southern Nigeria All 4 countries
Forest Based	11	7	Cassava, maize, beans, cocoyams	Southern Nigeria; Central & Western Nigeria
Rice-Tree Crop	1	2	Rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work	Central & Western Kenya; Northern Nigeria
Highland Perennial	1	8	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work	Central Kenya
Highland Temperate - mixed	2	7	Wheat barley, tef, peas, lentils, broadbeans, rape, potatoes, sheep, goats, livestock, poultry, off-farm work	Central Kenya All four countries
Root Crop	11	11	Yams, cassava, legumes, off-farm work	Southern Nigeria
Cereal-Root Crop mixed	13	15	Maize, sorghum, millet, cassava, yams, legumes, cattle	Kenya, Northern Nigeria
Maize Mixed	10	15	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work	Western Kenya; northern & central Nigeria
Large Commercial & Smallholder	5	4	Maize, pulses, sunflower, cattle, sheep, goats, remittances	Central & Western Kenya; Other countries
Agro-Pastoral Millet/Sorghum	8	8	Sorghum, pearl millet, pulses. sesame, cattle, sheep, goats, poultry, off-farm work	Niger, Northern Nigeria; northwestern Senegal
Pastoral	14	7	Cattle, camels, sheep, goats, remittances	Niger, Northern Nigeria, northern Kenya
Sparse (Arid)	17	1	Irrigated maize, vegetables, date palms, cattle, off-farm work	Northern Nigeria;
Coastal Artisanal Fishing	2	3	Marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, off-farm work	Southern Nigeria
Urban Based	little	3	Fruit, vegetables, dairy, cattle, goats, poultry, off-farm work	Urban areas, all countries

Source: Dixon et al. (2001) - http://www.fao.org/docrep/003/Y1860E/y1860e04.htm

Sub-Saharan Africa Farming systems



Source: Dixon et al. (2001) - http://www.fao.org/docrep/003/Y1860E/y1860e04.htm

SOUTH ASIA FARMING SYSTEMS

Farming Systems	Land Area (% of region)	Agric. Popn.(% of region)	Principal Livelihoods	Case study representing farming systems
Rice	7	17	Wetland rice (both seasons), vegetables, legumes, off-farm activities	Central & Southern India
Coastal Artisanal Fishing	1	2	Fishing, coconuts, rice, legumes, livestock	India coastal areas
Rice-Wheat	19	33	Irrigated Rice, wheat, vegetables, livestock including dairy, off-farm activities	Central & western states & West Bengal states
Highland Mixed	12	7	Cereals, livestock, horticulture, seasonal migration	Northern India
Rainfed Mixed	29	30	Cereals, legumes, fodder crops, livestock, off-farm activities	Central India
Dry Rainfed	4	4	Coarse cereals, irrigated cereals, legumes, off-farm activities	
Pastoral	11	3	Livestock, irrigated cropping, migration	Rajasthan India
Sparse (Arid)	11	1	Livestock where seasonal moisture permits	
Sparse (Mountain)	7	0.4	Summer grazing of livestock	
Tree Crop	Dispersed	1	Export or agro-industrialcrops, cereals, wage labour	
Urban Based	<1	1	Horticulture, dairying, poultry, other activities	

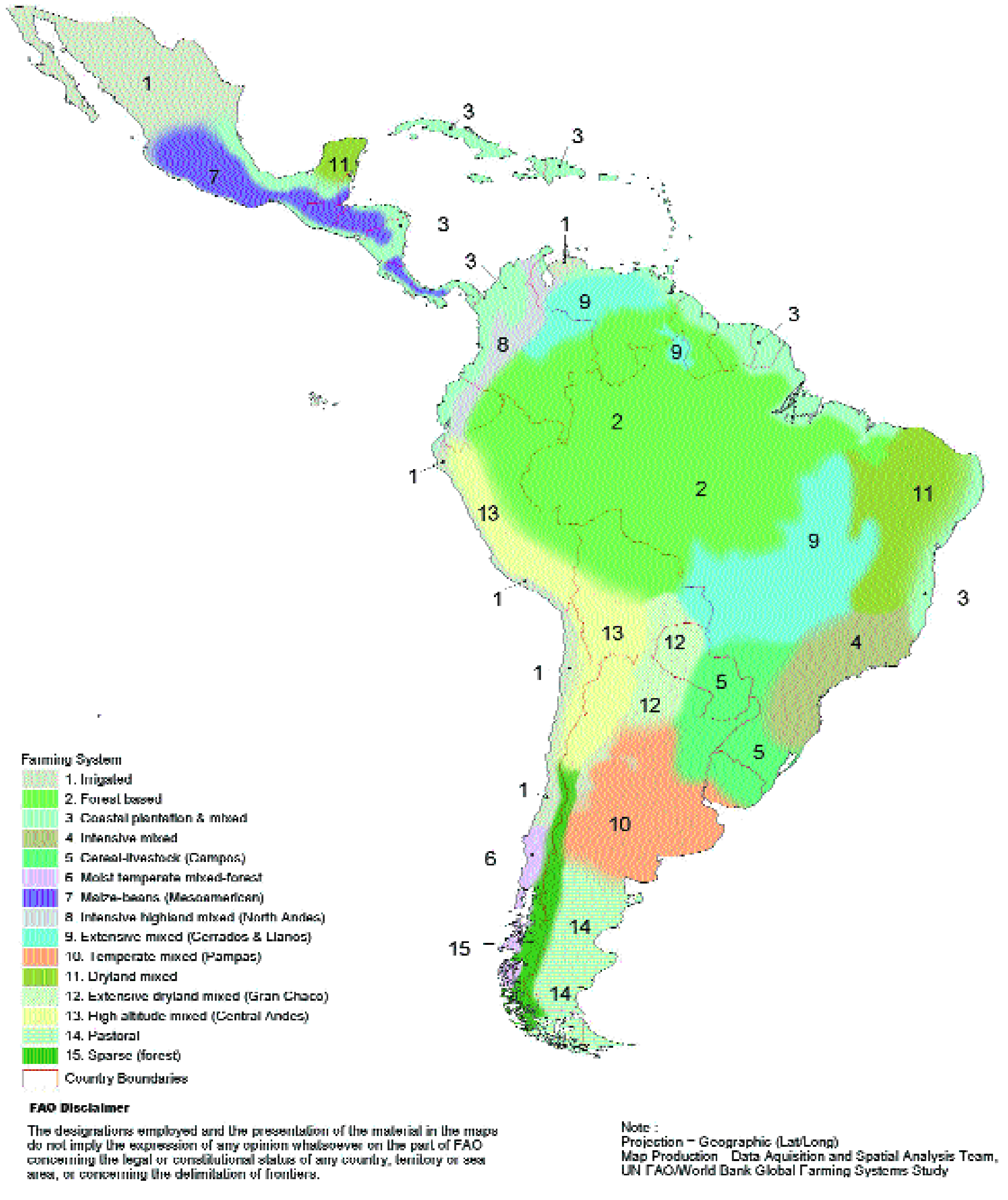
Source: http://www.fao.org/docrep/003/Y1860E/y1860e07.htm

Latin America & Caribbean farming systems

Farming Systems	Land Area (% of region)	Agric. Pop (% of region)	Principal Livelihoods	Case country representing farming systems
Irrigated	10	9	Horticulture, fruit, cattle	Western Argentina
Forest Based	30	9	Subsistence/cattle ranching	North-eastern Argentina
Coastal Plantation and Mixed	9	17	Export crops/tree crops, fishing, tubers, tourism	South-eastern Argentina
Intensive Mixed	4	8	Coffee, horticulture, fruit, off-farm work	
Cereal-Livestock (Campos)	5	6	Rice & livestock	Northern Argentina
Moist Temperate Mixed-Forest	1	1	Dairy, beef, cereals, forestry, tourism	Northern Argentina
Maize-Beans Mesoamerican)	3	10	Maize, beans, coffee, horticulture, off-farm work	
Intensive Highlands Mixed (Northern Andes)	2	3	Vegetables, maize, coffee, cattle/pigs, cereals, potatoes, off-farm work	North-eastern Argentina
Extensive Mixed (Cerrados & Llanos)	11	9	Livestock, oilseeds, grains, some coffee	Eastern Argentina
Temperate Mixed (Pampas)	5	6	Livestock, wheat, soybean	Central Argentina
Dryland Mixed	6	9	Livestock, maize, cassava, wage labour, seasonal migration	Patagonia Argentina
Extensive Dryland Mixed (Gran Chaco)	3	2	Livestock, cotton, subsistence crops	
High Altitude Mixed (Central Andes)	6	7	Tubers, sheep, grains, llamas, vegetables, off-farm work	
Pastoral	3	1	Sheep, cattle	
Sparse (Forest)	1	<1	Sheep, cattle, forest extraction, tourism	
Urban Based	<1	3	Horticulture, dairy, poultry	

Source : http://www.fao.org/docrep/003/Y1860E/y1860e09.htm#P3_30

Latin America and Caribbean Farming systems



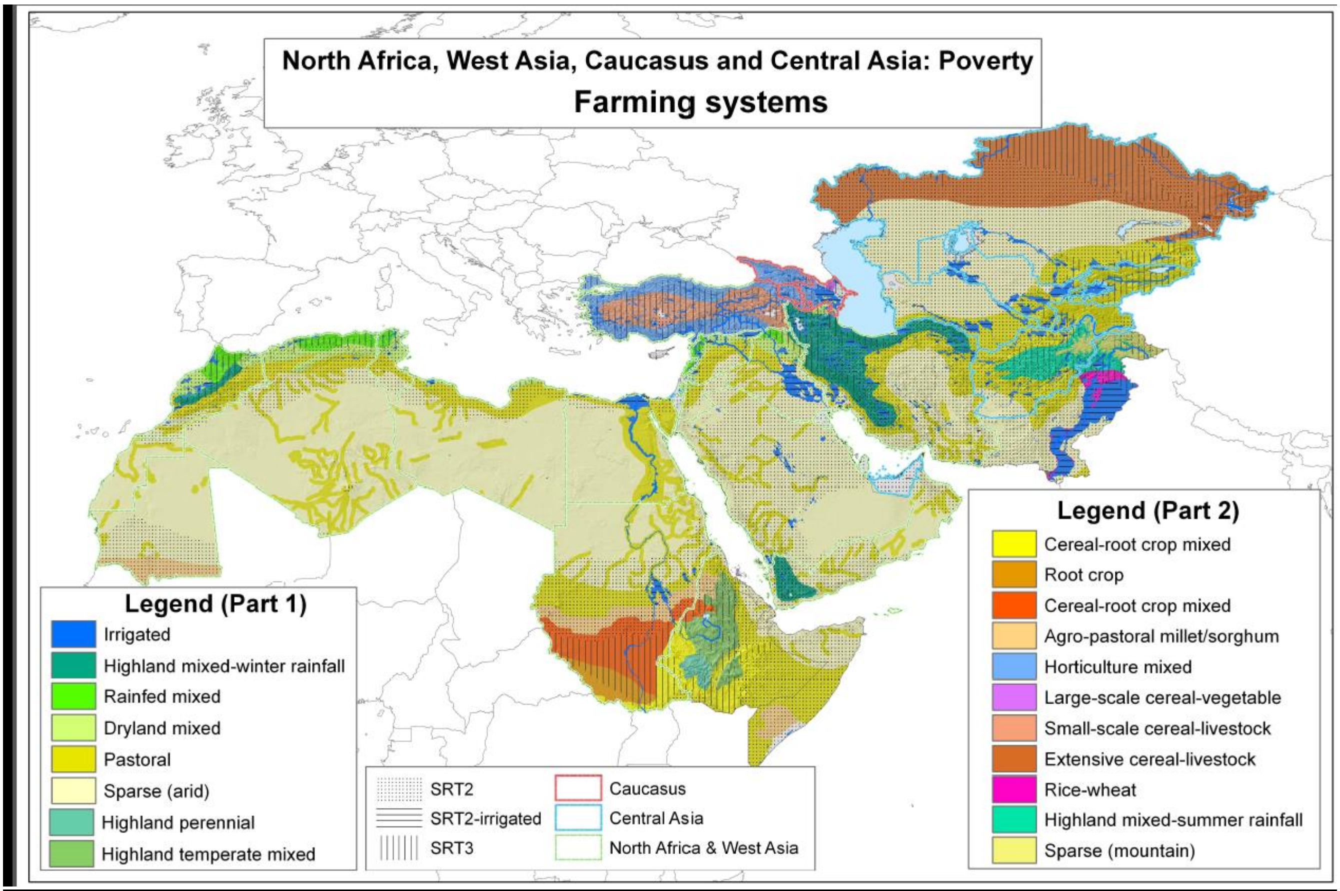
Source: Dixon et al. (2001) - http://www.fao.org/docrep/003/Y1860E/y1860e09.htm#TopOfPage

East Europe & Central Asia farming systems

Farming system	% of land area	% of population	Agricultural Household Livelihoods	Corresponding areas in Uzbekistan
Irrigated	1	4	Cotton, wheat, rice, off-farm, other cereals, fruit, vegetables	North-western, central and eastern
Mixed	4	18	Wheat, maize, oilseeds, barley, livestock	Central and Eastern
Forest based livestock	3	5	Fodder, hay, cereals, potatoes	minor
Horticultural mixed	3	11	Wheat, maize, oilseeds, fruit, intensive extensive vegetables, livestock, off-farm income	Eastern
Large-scale cereal vegetable	4	16	Wheat, barley, maize, Moderate - Vegetable sunflower, sugarbeet, extensive vegetables	minor
Small-scale cereal livestock	1	4	Wheat, barley, sheep, Livestock and goats	Central
Extensive cereal-livestock	18	15	Wheat, hay, fodder, Moderate - Cereal-Livestock cattle, sheep	minor
Pastoral	3	10	Sheep, cattle, cereals, fodder crops, potatoes	Southern and South-Eastern
Sparse (cold)	52	2	Rye, oats, potatoes, forestry	minor
Sparse (arid)	6	8	Barley, sheep	Central
Urban	<1	7	Vegetable, poultry	Mainly, north-western and eastern

Source: Dixon et al. 2001

NENA and Central Asia farming systems



Source: de Pauw and Altassi (2011) based on Dixon et al. (2001)
http://crp11.icarda.cgiar.org/crp/public/files/maps/Farming_Systems_CWANA.pdf