

Drivers of farm-level adaptation to climate change in Africa: an evaluation by a composite index of potential adoption

Silvestre García de Jalón · Ana Iglesias · Andrew P. Barnes

Received: 31 July 2014 / Accepted: 24 November 2014 / Published online: 17 December 2014
© Springer Science+Business Media Dordrecht 2014

Abstract Over recent decades, there has been increasing levels of research dedicated to assess drivers of farm-level uptake of adaptation strategies to climate change. The main purpose of this research being to determine how policy intervention can most effectively increase adoption. This paper aims to synthesise this past research in order to scale up uptake of farm-level adaptation strategies through a composite index of potential adoption in Africa. In doing so, we review the estimated coefficients of econometric regressions in 42 case studies published in peer-review journals to identify the factors that regularly explain adoption. We find that these common factors can be grouped into seven components, that is human capital, financial resources, infrastructure and technology, social interaction and governance, food security, dependence on agriculture and attitudes towards the environment. Using national-level indicators of these seven categories, we develop a composite index to inform potential adoption and test the robustness of the index in an in-depth sensitivity analysis. The results show that the highest likelihood of adoption of farm-level adaptation strategies is in Northern African countries namely Tunisia, Egypt, Algeria and Morocco and in Southern African countries such as South Africa and Botswana. Conversely, they indicate that the lowest likelihood of adoption is situated in nations of the Sahel and Horn of Africa and in nations that have recently experienced conflict. We conclude that adoption is associated predominantly with governance, civil rights, financial resources and education. However, it is not necessarily driven by the magnitude of climate change impacts on agricultural production.

S. García de Jalón (✉) · A. Iglesias
Department of Agricultural Economics and Social Sciences, Technical University of Madrid, Avda. Complutense s/n, Ciudad Universitaria, 28040 Madrid, Spain
e-mail: silvestre.jalon@upm.es

A. Iglesias
e-mail: ana.iglesias@upm.es

A. P. Barnes
Reader in Innovation and Behavioural Change Scotland's Rural College (SRUC), West Mains Road, Edinburgh EH9 3JG, UK
e-mail: Andrew.Barnes@sruc.ac.uk

Keywords Adaptation strategies · Adoption · Africa · Climate change · Composite index · Farm-level

1 Introduction

The sustainable development of agriculture in Africa as well as its contribution to food security and economic growth is threatened by climate change (Parry et al. 2004; Lobell et al. 2008; Ngiigi 2009). The United Nations Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) (Niang and Ruppel 2014) foresees with a high level of confidence that climate change along with non-climate drivers will exacerbate vulnerability of agricultural systems due to an increase in temperature and changes in precipitation patterns. Rural communities are especially vulnerable due to an elevated dependence on agriculture and a limited resilience to cope with novel situations (Schmidhuber and Tubiello 2007). Consequently, smallholder farmers have no alternative but to adapt their livelihood systems to changing climatic conditions (Ngiigi 2009).

IPCC AR5 highlights the importance of farm-level adaptation strategies in order to reduce climate change vulnerability and to make farm-households better able to adjust to the changing climate avoiding or diminishing potential damages (Niang and Ruppel 2014). According to the classification of AR5 (Intergovernmental Panel on Climate Change IPCC 2014), farm-level adaptation strategies include the category of technological (e.g. changing crop and livestock varieties, water management innovations, conservation agriculture, early warning systems), ecosystem-based category (e.g. afforestation and reforestation), educational (e.g. extension services, communication through media) and behavioural (e.g. soil and water conservation, changing cropping practices, patterns and plant dates, reliance on social networks).

IPCC AR5 also points out the potential that public and private institutions have to enhance adoption of farm-level adaptation strategies. In this context, in all regions of the continent, national governments are initiating governance systems and developing numerous policies and programmes (Niang and Ruppel 2014). These frequently aim at integrating adaptation to climate change into policies related to sustainable development, food security and poverty (Africa Adaptation Programme AAP 2013; Beddington et al. 2012; Dixon et al. 2003; International Fund for Agricultural Development IFAD 2013) and usually target those people most vulnerable to climate change (Nzuma et al. 2010; Downing et al. 1997). An example of this is the Africa Adaptation Programme (AAP) (2013) by the United Nations Development Programme (UNDP) which has recently implemented a programme with the purpose of enhancing adaptive capacity, promoting early adaptation action and laying foundations for long-term investment in order to increase resilience of farm households to climate change.

These policies are often developed at elevated scales such as the whole African continent and are based on the information provided by case studies conducted at the local level (United Nations Framework Convention on Climate Change (UNFCCC) 2011). However, since policies are frequently based on a small number of case studies, their effectiveness may be rather low due to the high heterogeneity of factors affecting uptake of adaptation strategies. In this context, the AR5 highlights with high confidence the need for enhancing and scaling up adaptation responses at the local level including principles for good practice and integrated approaches to adaptation (Niang and Ruppel 2014). Therefore, assessing farm-level adoption through an approach which covers the whole African continent can provide helpful information to develop policies to enhance adaptive capacity for coping with a variety of risks associated with climate change (Nhemachena and Hassan 2007). This study develops a composite index of the uptake of adaptation in Africa based on numerous local-level case

studies. Thus the composite index provides an understanding of the probability of farm-level adoption in the different regions and helpful information to design policies and programmes at regional scales. Nevertheless, the accuracy of estimates when scaling up adoption can be limited by the variability in climate change impacts across the continent and natural limits to adaptation such as soil quality. This limitation points out the need for a large number of local-level case studies in order to identify reliable patterns across the case studies.

In order to provide a better understanding of how farm-level adoption can be improved through policy intervention, there has been a growing interest around the drivers of uptake of adaptation strategies. In this context, particular attention has recently been placed upon analysing the effect of sociodemographics and farm characteristics on adoption of farm-level adaptation measures (e.g. Gbetibouo 2009; Deressa et al. 2009; Bryan et al. 2009; Silvestri et al. 2012). These determinants can act as biophysical, economic or social motivations or barriers to the potential uptake of recommended agricultural practices against climate change. Since smallholders represent the most vulnerable stakeholders and implementation of adaptation will ultimately proceed on a local or individual scale, understanding adoption of farm-level adaptation strategies seems to be an appropriate first step for a bottom-up approach as well as to identify the drivers behind the uptake of adaptation.

Previous reviews of farm-level adoption of recommended agricultural practices have been conducted to explore those factors that regularly explain adoption (e.g. Baumgart-Getz et al. 2012; Knowler and Bradshaw 2007). Typically, these studies analyse the estimated coefficients of the independent variables of econometric regressions conducted in previous studies. These studies usually attempt to establish common baselines to inform policies that can enhance adoption of recommendable agricultural practices considering the results of numerous studies. However, these reviews often do not attempt to map these common baselines in order to identify regions which are more or less likely to adopt certain agricultural practices. Whilst numerous studies have assessed and regionalised adaptive capacity and vulnerability to climate change in Africa (e.g. Naumann et al. 2014; Thornton et al. 2006; Brooks et al. 2005), there is clearly a gap in the literature on studies attempting to estimate spatially explicit adoption of farm-level adaptation strategies with the African farming context. Accordingly, this work aims to bridge this gap between the large body of literature on adoption of farm-level adaptation strategies and studies that regionalise adaptive capacity and vulnerability to climate change.

The aim of this paper is to provide a regionally explicit composite index that explains the likelihood of adoption of farm-level adaptation strategies. Thus, it provides an upscaled assessment of potential adoption for the whole African continent.

2 Data and methods

2.1 Framework

The methodological process aims to provide a transparent construction of a robust composite index that can be easily replicated in other regions. It can be described in the following six methodological steps:

- i. Selection of case studies in Africa that assess through econometric regressions adoption of farm-level adaptation strategies
- ii. Identifying independent variables in econometric regressions of past research that regularly explain adoption
- iii. Grouping these independent variables into components

- iv. Selecting indicators from public databases that define each component of the composite index
- v. Estimating the likelihood of adoption of farm-level adaptation strategies through the calculation of the API in Africa
- vi. Analysing limitations of the composite index and sources of uncertainty by a sensitivity analysis

2.2 Selection of independent variables that regularly explain adoption and relevance

The selection of indicators of a composite index should be based on the analytical soundness, measurability and relevance to the phenomenon being measured and their relationship to these phenomena (OECD 2008). In this study, the selection of indicators was based on the review and synthesis of 100 econometric regressions conducted in 42 case studies. All case studies were conducted in Africa, published in peer-review journals and presented the common objective of assessing by econometric regressions the influence of socioeconomic factors on the uptake of farm-level adaptation strategies. Thereby, we analysed the estimated coefficients of the econometric regressions presented in the studies in order to identify those independent variables that regularly explain adoption in Africa and consequently could be used to estimate a composite index of potential adoption.

The table in Appendix A presents these case studies and describes their sample size, approach and evaluated adaptation strategies through econometric regressions. The case studies covered the African continent and the majority of them used a logit or probit econometric approach. Following the typology of adaptation strategies defined by Smit and Skinner (2002), the strategies of the case studies broadly could be classified into two major groups. The first group deals with adoption of technological developments which includes adaptation strategies such as crop development of new crop varieties (17 % of econometric regressions), technological innovations (6 %) and agrochemicals (11 %). The second group is adoption of farm production practices and includes adaptation strategies such as changes in farm production (16 %), land use (7 %), land topography (10 %), irrigation and water conservation (12 %), timing of operations (7 %) organic fertilisers (5 %), and others (9 %).

The next step was to group into components the selected independent variables that regularly explain adoption of adaptation strategies. The fact that all case studies were conducted at the farm level and in the same region made the identification of components more consistent and reliable.

Through publically available databases (Faostat, Worldbank, Aquastat and Kaufmann, Kray and Mastruzzi data set), national-level indicators of the identified components were used to calculate the composite index. The selection of these national-level indicators was based on three criteria: (i) the indicator had to represent a quantitative or qualitative aspect of both uptake of adaptation and the identified components, (ii) data needed to be available in public databases and (iii) each indicator had to have at least 50 % of the countries without missing data (Naumann et al. 2014; OECD 2008). This emphasis on public databases ensures that the final result can be validated, reproduced and improved with new data (Vincent 2004; Naumann et al. 2014). Moreover, the divergence of the independent variables of the econometric regressions towards a positive and significant influence on adoption was also considered to select national-level indicators of the components.

For those countries that presented missing data, the values were completed from secondary sources and from data from neighbouring countries with similar biophysical and socioeconomic characteristics. For biophysical characteristics, the selection of substituted

countries was based on climate characteristics and on the proximity between countries. For socioeconomic characteristics, the selection was based on similar values of GDP per capita and on cultural factors, such as similarities in historical tradition, religion distribution and laws. It is important to highlight that this substitution of missing values can be an important source of uncertainty in the final output of the composite index. For this reason, the effect of data substitution should be tested in the sensitivity analysis and the interpretation of the results should be discussed considering these sensitivities. Vincent (2004) recommends the substitution for missing values when it is unavoidable, given the indicator data availability, and points out the risk of basing these substitutions on subjectivity alone. He claims that the only solution is to make such choices transparent, in order to enable effective critical evaluation of the robustness of the index.

2.3 Calculating the adoption potential index (API) of farm-level adaptation strategies

Once collated, the national-level indicators needed to be normalised to allow direct comparison between results among countries, as most indicators had different measurement units. Normalisation was calculated considering the minimum and maximum value of each indicator across all countries to guarantee that all indicators had an identical range between 0 and 1 following the same methodology as in Naumann et al. (2014). Similar methodologies have been widely used for calculating composite indexes (e.g. Brooks et al. 2005; OECD 2008; Thornton et al. 2006; Vincent 2004). For indicators with a positive correlation to the overall potential adoption index, the normalised value (NI_i) was calculated according to the following linear transformation:

$$NI_i = \frac{I_i - I_{\min}}{I_{\max} - I_{\min}} \quad (1)$$

where I_i is the indicator value for a generic country i , and I_{\min} and I_{\max} the minimum and maximum value across all countries i . For indicators with a negative and statistically significant correlation with the overall composite index, the normalised values of the index were reversed. In this way, all normalised indicators (NI_i) had values ranging between 0 (lowest potential adoption of farm-level adaptation strategies) and 1 (highest potential adoption).

For each country, any of the j ($j=1, \dots, 7$) components (C) were calculated as the mean of the normalised indicators NI_i that define each component (Equation 2). Finally, Equation 3 shows how the overall API of each country was calculated as a weighted aggregation of the components.

$$C_j = \frac{1}{n} \sum_{i=1}^n NI_i \quad (2)$$

$$API_i = \sum_{j=1}^7 W_j C_{i,j} \quad (3)$$

where W_j are the weights assigned for the j component (with $\sum W_j=1$) and $C_{i,j}$ are the components for each country. Thus, the scores of the API are the relative index value of a country with respect to the remainder of the countries. These values range from 0 to 1, where 0 represents the lowest likelihood of adoption of farm-level adaptation strategies and 1 is associated with the highest likelihood.

As no perfect weighting and aggregation convention exists for developing composite indexes (Arrow 1963), it was necessary to test the robustness and stability of the weights. Following the study by Naumann et al. (2014), we used three different weighting schemes to test the influence of weighting on the API: equal weights among components (equal weights), weighting scheme according to the number of indicators in each component (proportional weights) and random weights (using the Monte Carlo method with 1000 simulations).

2.4 Sensitivity and sources of uncertainty

Sensitivity analysis is normally used to assess the robustness and validity of composite indicators (OECD 2008). It focuses on how uncertainty in the input factors (i.e. indicators, weighting and aggregation) propagates through the overall structure of the index. Typically, the sources of uncertainty are derived from the subjective judgements of the researcher for constructing the index (OECD 2008). In this study, the main sources of uncertainty were derived from two subjective judgements: (i) the selection of the aggregation and weighting methods and (ii) the substitution of country data for countries that presented missing values. In order to analyse the uncertainty of these two sources, different Monte Carlo experiments were computed to assess the contribution of any individual source of uncertainty to the output variance. This methodology is based on multiple evaluations of the model with different weighting and aggregation schemes that generate different probabilistic density functions of model outputs (Naumann et al. 2014). Furthermore, the robustness of the index was also analysed by the stability of the country rankings assigned by the index value in the sensitivity analysis. Thereby, the shift in country rankings reflected the uncertainty associated to each input factor.

The sensitivity to the weighting scheme and aggregation of components was tested by analysing the effect on the composite index of all countries when assigning random weights to the components. In doing so, 1000 repetitions were done for the values of the component weights in order to compute the API. The other source of uncertainty, i.e. substitution of missing data, assessed the effect on the final output of the API by assigning random values for indicators of those countries that presented missing data. Thereby for each weighting scheme, 1000 repetitions were computed assigning random values to those countries that presented missing data.

3 Results

3.1 Selection of independent variables that regularly explain adoption of adaptation strategies

The first step of the methodological process was to select case studies in Africa assessing adoption of farm-level adaptation strategies through econometric regression techniques. Subsequently, the estimated coefficients were used to identify those independent variables that are regularly used to explain adoption. Among the 100 analysed econometric regressions, 26 independent variables were selected (Table 1). Those independent variables that were infrequently used were excluded from the analysis as they were unlikely to provide much information or to show a pattern across empirical studies (Knowler and Bradshaw 2007). Table 1 describes detailed information about the sign and significance of each independent variable in the econometric regressions of the case studies. Whilst several statistical thresholds indicating significance were presented across the studies, we selected 5 % as the cut-off for our analysis.

Table 1 Frequency analysis showing the results for significance and sign on estimated coefficients of 100 econometric regressions in 42 case studies assessing factors influencing adoption of climate change adaptation strategies in Africa

Component	Independent variables	Sign (+)	Sign (–)	Total significant	Total insignificant	Total
Human capital	Gender (1=male)	22 (92 %)	2 (8 %)	24 (30 %)	55 (70 %)	79
	Age	16 (59 %)	11 (41 %)	27 (42 %)	38 (58 %)	65
	Education	30 (88 %)	4 (12 %)	34 (39 %)	53 (61 %)	87
	Experience	13 (87 %)	2 (13 %)	15 (43 %)	20 (57 %)	35
	Household size	23 (79 %)	6 (21 %)	29 (34 %)	57 (66 %)	86
Financial resources	Gross farm income	9 (64 %)	5 (36 %)	14 (52 %)	13 (48 %)	27
	Credit access	16 (100 %)	0 (0 %)	16 (32 %)	34 (68 %)	50
	Wealth indicators	4 (100 %)	0 (0 %)	4 (18 %)	18 (82 %)	22
	High productivity soil	6 (55 %)	5 (45 %)	11 (37 %)	19 (63 %)	30
	Farm size	25 (68 %)	12 (32 %)	37 (47 %)	41 (53 %)	78
	Tenure (1=owned)	11 (85 %)	2 (15 %)	13 (34 %)	25 (66 %)	38
	Livestock ownership	17 (85 %)	3 (15 %)	20 (44 %)	25 (56 %)	45
Infrastructure and technology	Infrastructure	6 (67 %)	3 (33 %)	9 (41 %)	13 (59 %)	22
	Distance to paved road	6 (32 %)	13 (68 %)	19 (44 %)	24 (56 %)	43
	Technology	5 (100 %)	0 (0 %)	5 (50 %)	5 (50 %)	10
Social interaction and governance	Extension/technical assistance	26 (90 %)	3 (10 %)	29 (45 %)	36 (55 %)	65
	Participation with institutions	3 (100 %)	0 (0 %)	3 (43 %)	4 (57 %)	7
	Source of information	2 (100 %)	0 (0 %)	2 (29 %)	5 (71 %)	7
	Access to climate information	10 (100 %)	0 (0 %)	10 (32 %)	21 (68 %)	31
	Kin as partners	0 (0 %)	1 (100 %)	1 (14 %)	6 (86 %)	7
	Membership in organisations	10 (91 %)	1 (9 %)	11 (41 %)	16 (59 %)	27
Food security	Food security	5 (71 %)	2 (29 %)	7 (50 %)	7 (50 %)	14
Dependence on agriculture	Off-farm activities/income	10 (67 %)	5 (33 %)	15 (31 %)	34 (69 %)	49
Attitudes towards the environment and climate change	Soil erosion rate	3 (100 %)	0 (0 %)	3 (75 %)	1 (25 %)	4
	Concern about the environment	0 (na)	0 (na)	0 (0 %)	2 (100 %)	2
	Experienced climate change impacts	3 (75 %)	1 (25 %)	4 (80 %)	1 (20 %)	5
Total				362 (39 %)	573 (61 %)	935

The next step was to aggregate the independent variables into components regarding similarities. Thereby, aggregation was undertaken into seven components in terms of human capital, financial resources, infrastructure and technology, social interaction and governance, food security, dependence on agriculture and attitudes towards the environment.

Human capital is the component most frequently assessed across the case studies. Education, farming experience and household size are the independent variables that seem to show better convergence towards a positive and significant influence on the uptake of adaptation strategies. Despite the fact that farmer's age is frequently assessed, our results show

that its correlation with adoption is very questionable, confirming the findings by Knowler and Bradshaw (2007). Approximately 58 % of the econometric regressions found insignificant relationships between age and adoption (e.g. Asfaw and Admassie 2004; Di Falco et al. 2011). Among the significant relationships (42 %), 59 % had a positive effect (e.g. Gebrehiwot and van der Veen 2013; Oben Tabi et al. 2012) and 41 % a negative effect (e.g. Somda et al. 2002; Marenya and Barrett 2007). In the case of gender, approximately 70 % of the econometric regressions found a statistically insignificant relationship.

The independent variables within financial resources are regularly assessed but do not seem to reflect plain convergence towards a positive and significant influence on the adoption. Credit access, wealth indicators and livestock ownership are the variables that show the highest convergence. Farm size is the independent variable most frequently assessed of the component. Among the significant relationships (47 %), around 68 % of the regressions found a positive effect and 32 % a negative effect. Within the component of infrastructure and technology, the variable of high availability of technology in the farm (i.e. technology) presents the highest convergence towards a positive and significant correlation.

The component of social interaction and governance presented the highest positive and significant correlation with adoption. The independent variables most frequently assessed within the component are access to extension services, climate information and membership of organisations. All these independent variables are related to networking capacities and numerous studies have revealed both positive and significant influence on adoption (e.g. Bryan et al. 2009; Deressa et al. 2009; Abdulai et al. 2011).

The independent variable of off-farm activities represents the relative dependence on agriculture. Its relationship with adoption does not seem very clear as approximately 67 % of the regressions have a positive and significant relationship and in 33 % of the cases, the influence was negative and significant. The components of food security and attitudes towards the environment and climate change are the least frequently assessed. In the case of food security, only seven regressions out of fourteen found a significant relationship. Finally, all independent variables within the attitude component seem to reflect a slight positive and significant relationship with adoption (e.g. Sidibé 2005; Okoye 1998; Shiferaw and Holden 1998; García de Jalón et al. 2013).

3.2 Selection of national-level indicators

The selection of indicators was carried out on the basis of the previous identification of components through the synthesis of econometric regressions of past research. This section shows the process of selecting indicators from public databases and explains the reasons of the selection. Table 2 summarises the selected national-level indicators and the source of the databases separated in the seven components. All African countries were included in the analysis with the exemption of Comoros, São Tomé and Príncipe, Seychelles and Western Sahara because of insufficient available data. In total, 28 national-level indicators from public databases were selected and aggregated in the seven components previously identified through the synthesis of past research.

Human capital basically includes indicators of education and density of population. Among the analysed econometric regressions, the independent variables of this component that show the highest convergence towards a positive and significant influence on adoption were education, farming experience and household size. Whilst literacy rate, school enrolment and progression of females to secondary school seem to be adequate indicators of education, household size reasonably matches with density of population.

Table 2 Potential national-level indicators for adoption of adaptation strategies to climate change

Components	Indicator	Description	Source
Human capital	Literacy rate	Literacy rate, adult total (percentage of people ages 15 and above)	World bank
	Entitlement of information	School enrolment, tertiary (percentage gross)	World bank
	Gender equality in education	Progression to secondary school, female (%)	World bank
	Density	Density of population	World bank
Financial resources	Economic power	GDP per capita	World bank
	Flexibility	Ease of doing business index	World bank
	Gender equality in labour market	Percentage female economically active population of total	Faostat
Infrastructure and technology	Isolation of rural communities	Access to electricity (percentage of population)	World bank
	Isolation of rural communities	Improved water source, rural (percentage of rural population with access)	World bank
	Agricultural infrastructure	Percentage of area equipped for full control irrigation actually irrigated	Aquastat
	Sanitation infrastructure	Improved sanitation facilities (percentage of population with access)	World bank
	Research and innovation	Scientific and technical journal articles per person	World bank
Social interaction and governance	Social diffusion of information	Internet users (per 100 people)	World bank
	Social diffusion of information	Mobile cellular subscriptions (per 100 people)	World bank
	Governance and regulatory framework	Political stability and absence of violence/terrorism	Kaufmann, Kray and Mastruzzi data set
	Governance and regulatory framework	Government effectiveness	Kaufmann, Kray and Mastruzzi data set
	Governance and regulatory framework	Regulatory quality	Kaufmann, Kray and Mastruzzi data set
	Governance and regulatory framework	Rule of law	Kaufmann, Kray and Mastruzzi data set
	Governance and regulatory framework	Control of corruption	Kaufmann, Kray and Mastruzzi data set
Food security	Nutritional status	Percentage of the total population undernourished	Aquastat
	Nutritional status	Malnutrition prevalence, weight for age (percentage of children under 5)	World bank
Dependence on agriculture	Dependence on agriculture	Percentage of Agricultural area	Faostat
	Dependence on agriculture	Percentage agricultural population	Faostat
	Dependence on agriculture	Agriculture, value added (Percentage of GDP)	World Bank
	Agricultural potential	Cereal yield (kg per hectare)	World Bank

Table 2 (continued)

Components	Indicator	Description	Source
Attitudes towards the environment	Attitudes towards the environment	Percentage organic agriculture area as percentage of cultivated area	Faostat
	Environmental stress	Percentage forest area of total area	Faostat
	Environmental stress	Freshwater withdrawal as percentage of total actual renewable water resources (%)	Aquastat

The component of financial resources includes GDP per capita, ease of doing business and economically active females. All of these are clear indicators of financial capital. Within the component of infrastructure and technology, the indicators of isolation of rural communities match relatively well with distance to market. Whilst irrigation infrastructure and sanitation facilities match with infrastructure, scientific and technical journal articles per person match with technology.

The selected indicators of social interaction and governance were public institutions, agricultural networks and interactions between farmers and public institutions. Thereby, the indicators of this component were related to dissemination of information, such as mobile cellular and internet users and to governance and regulatory frameworks, such as political stability, governance effectiveness and regulatory quality.

The indicators used for food security were population undernourished and malnutrition prevalence among children. The indicators of dependence of agriculture were agricultural population, area and percentage of GDP and potential cereal yield. The component of attitudes towards the environment was represented by indicators of environmental stress such as percentage of freshwater withdrawal and forest area and by the percentage of organic area of cultivated area.

The indicators' ease of doing business index, population undernourished, malnutrition prevalence between children, agricultural population and value added of agriculture to GDP were reversed because they had a negative and statistically significant correlation with the adaptation adoption index.

3.3 Estimating regional potential adoption of farm-level adaptation strategies

In order to understand the derivation of the API, it is useful to analyse the value of the components separately (Naumann et al. 2014). Figure 1 shows the value of the components for each of the 49 African countries.

Tunisia, Egypt, South Africa, Morocco and Algeria present the highest values of the composite index. The total sum of the normalised indicators (0–1) of these countries is close to or higher than 4. They have the highest value of human capital, infrastructure, food security and attitudes towards the environment. On the contrary, the five countries with the lowest values are Chad, Eritrea, Niger, Democratic Republic of Congo and Somalia with API values close to 0.2. These countries present the lowest value of financial resources, social interaction and governance, food security and dependence on agriculture.

Figure 2 presents the map by deciles of the API. According to the geographical divisions of the African Union, Northern Africa indicates the highest likelihood of adoption of farm-level adaptation strategies followed by Southern Africa, Western Africa, Central Africa and lastly Eastern Africa. It is noteworthy to highlight that our results emphasise the fact that climate

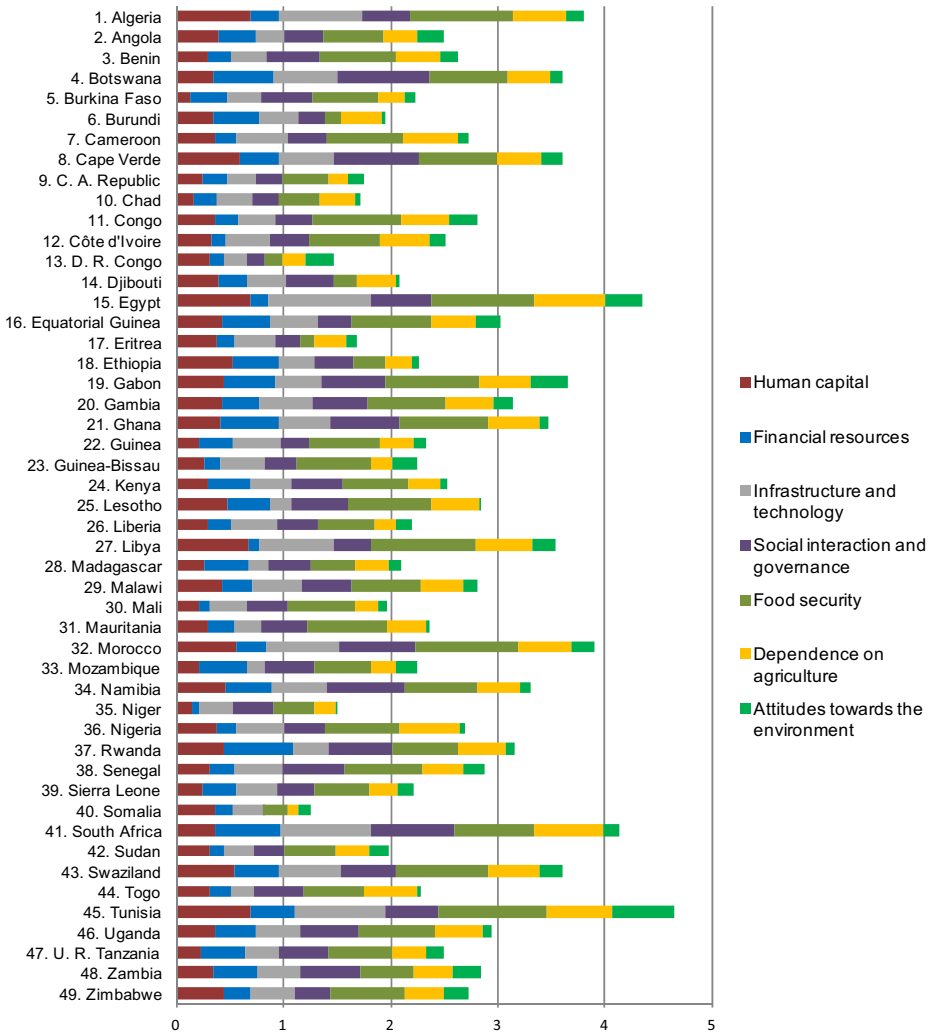


Fig. 1 Adoption potential index for the 49 African countries disaggregated in their seven components: human capital, financial resources, infrastructure and technology, social interaction and governance, food security, dependence on agriculture, and attitudes towards the environment

change impacts on agriculture and likelihood of adoption seem not to be strongly correlated. Accordingly, whilst climate change projections seem to indicate that the Sahelian Belt and some parts in Northern and Southern Africa will suffer the largest impacts on agricultural yields (Fischer et al. 2005; Schlenker and Lobell 2010; Thornton et al. 2006; Niang and Ruppel 2014; Parry et al. 2004), our index shows that the Sahelian Belt has the lowest probability of adoption and Northern and Southern Africa the highest probability.

3.4 Sensitivity analysis of the composite index

Sensitivity analysis was used to evaluate the robustness and validity of the results by estimating the degree of uncertainty associated with the construction of the API. It is also

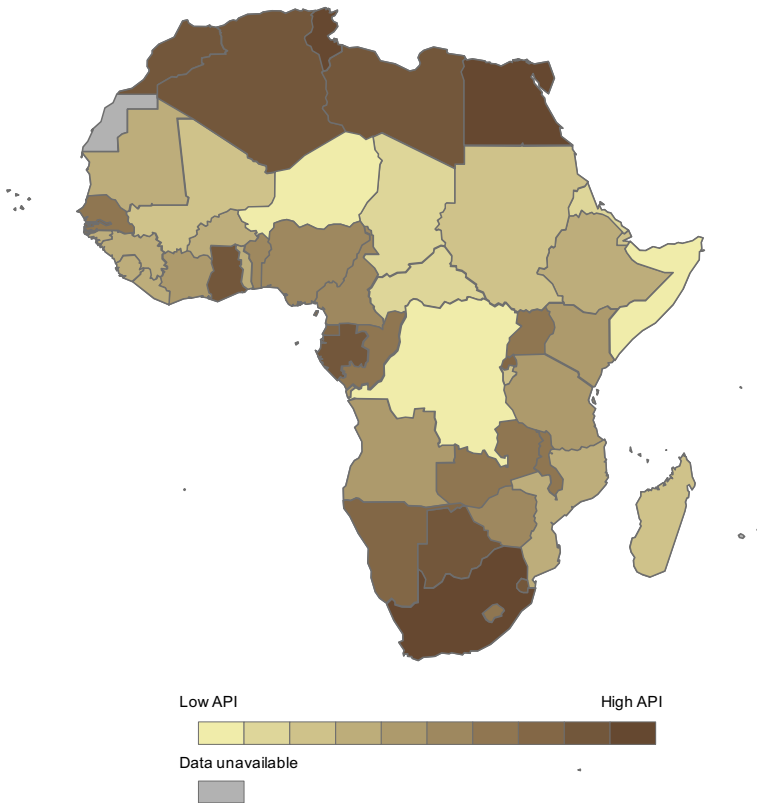


Fig. 2 Map by deciles of the adoption potential index in Africa

helpful to identify which countries were favoured or weakened under the different assumptions of the index.

The main sources of uncertainty of the API index were derived from the selection of the aggregation and weighting methods and the substitution of country data for countries that presented missing values. Figure 3 shows the sensitivity of both sources of uncertainty in the API values and country ranks. Broadly, API values and country ranks in the sensitivity to weights and aggregation were less dispersed and consequently less sensitive than in the sensitivity to substitution of missing data.

Within the sensitivity to substitution of missing data, the weighting schemes of equal and proportional weights were notably more robust than the random weights scheme. These results suggest that the schemes of equal and proportional weights were more robust with respect to missing data. According to the output variance in the API values and country ranks, the proportional weights scheme was the most robust scheme followed by equal weights and random weights.

Overall, Fig. 3 demonstrates that our results are moderately robust since considering only the values inside the boxes, i.e. 50 % of the estimations, the ranking of the index among countries did not significantly vary except in the random weights scheme.

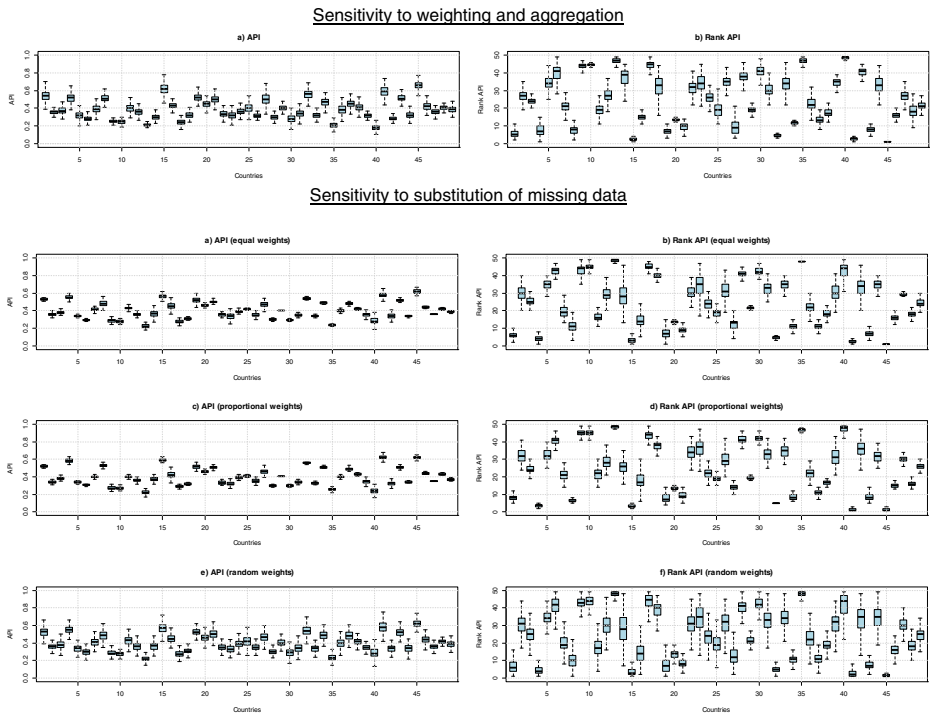


Fig. 3 Sensitivity of country adoption potential index values and rankings to weighting and aggregation (**a, b**) and to substitution of missing data (**c, d, e, f, g, h**). *Dashed lines* extend from the 5th to 95th percentile of estimations, *boxes* extend from the 25th to 75th percentile and *middle horizontal lines* within each box indicate the median for each country. The countries were numbered following their alphabetical order (see Fig. 1 for the corresponding names)

4 Limitations, implications and conclusions

This study presents an innovative approach to evaluating smallholders' uptake of adaptation strategies for the whole African continent. However, there are a number of limitations which need to be addressed.

Firstly, the selection of indicators is based on a synthesis of independent variables in numerous econometric regressions to evaluate different types of adaptation strategies. Thereby, all adaptation strategies were treated as if they were driven by the same independent variables. This limitation would have been avoided with a greater sample of case studies which would have allowed classifying adaptation strategies into more homogenous groups. This would lead to a higher accuracy of the composite index since different independent variables would have been used for different adaptation strategies. However, the number of case studies that are conducted in Africa and published in peer review journals is not large enough to enable this categorisation in terms of types of adaptation strategies or sub-regions of Africa. Consequently, extending this approach would require detailed scrutiny of non-published or grey literature on adoption which these authors did not have access to. Secondly, evaluating farm-level adoption entails an individual's behaviour in terms of the decision-making process.

This complicates the generalisation of adoption at higher scales due to the irrationality of human behaviour (Kiome and Stocking 1995). Furthermore, other factors such as cultural and behavioural barriers can play a crucial role in the uptake of adaptation (Nielsen and Reenberg 2010), but their inclusion in a national-level analysis seems to be very ambitious. In order to include a component of national-level attitudes, we selected indicators that reflect societal attitudes towards the environment, such as percentage of organic agriculture, forest area and freshwater withdrawal. Thirdly, our composite index was calculated as a weighted average of the identified components which assumes strong relationships among the indicators. Nevertheless, as there is no consensus on the selection of weights in composite indexes (OECD 2008), our index was computed by three different weighting schemes. Fourthly, the composite index only includes indicators related to socioeconomic factors and does not include indicators related to natural factors such as climate and soil characteristics or climate change impacts on agricultural production. This is due to the direct influence of the magnitude of climate change impacts, and natural factors on farm-level adoption are not very clear or have not been demonstrated in past research. This leads to considerable difficulty interpreting the results or establishing general patterns. Nevertheless, whilst it could be argued that better natural conditions would lead to higher adoption rate due to higher yields and resources to adapt, it may be that worse natural conditions would lead to higher adaptation needs and consequently to higher adoption rate. The final limitation was the unavailability of completed data in datasets. Despite one of our requirements to select indicators to have at least 50 % of the countries without missing data, and the total amount of missing data was not excessively high, the data of most of the selected indicators presented at least one country with a missing value.

Notwithstanding these limitations, the regional estimation of farm-level uptake of adaptation is an issue of international interest and can help policy makers to identify those regions where smallholder farmers are less likely to adapt to climate change and consequently suggesting where policy intervention is more necessary.

The results of the API show that whilst Northern and Southern Africa have the highest likelihood of adoption of farm-level adaptation strategies, Central, Eastern and Western Africa have the lowest probability. It is worthwhile to note that the five countries with the highest probability of adoption, i.e. Tunisia, Egypt, South Africa, Morocco and Algeria, border the Mediterranean Sea or have a Mediterranean climate. Conversely, the five countries with the lowest values are Chad, Eritrea, Niger, Democratic Republic of Congo and Somalia. With the exception of Democratic Republic of Congo, all of them share a Sahelian climate in which in the last decades, agriculture has suffered dramatic impacts from desertification and soil loss (Charney 1975; Giannini et al. 2008). Thus, our results emphasise that larger climate change impacts do not necessarily lead to higher probability of adoption, and there are other considerably more important drivers or limits to adoption such as lack of resources or low adaptive capacity.

Our results point out that war and conflict exacerbates a low rate of adoption of farm-level adaptation strategies. For instance, Democratic Republic of Congo and Somalia present the lowest API values and both countries have experienced numerous conflicts in the last decades. These results are in line with numerous studies that claim that conflicts aggravate a lower adaptive capacity and consequently a higher vulnerability to climate change (Brooks et al. 2005; Barnett and Adger 2007; Salehyan 2008).

The composite index developed in this study for assessing farm-level uptake of adaptation shares many things in common with climate change vulnerability studies conducted in Africa (e.g. Thornton et al. 2006; Naumann et al. 2014; Brooks et al. 2005). Farm-level adoption is strongly influenced by the adaptive capacity of the farm, and together with the exposure to

climate impacts determines the vulnerability to climate change (Smit and Wandel 2006). In line with our results, previous studies found that overall, most vulnerable African countries are located in the Sahel (Thornton et al. 2006; Naumann et al. 2014; Brooks et al. 2005). In this way, our results seem to indicate that farm households of Sahelian countries such as Burkina Faso, Chad, Eritrea, Ethiopia, Niger, Somalia and Sudan are less likely to adopt adaptation strategies despite the adverse impacts of climate change that they are currently suffering and are expected to be aggravated in the coming decades (Schlenker and Lobell 2010).

The approach provides a transparent procedure for the estimation of a composite index in order to assess farm-level adoption and offers a robust methodology for the identification of regions where smallholder farmers are less likely to adopt adaptation strategies. Thus, the composite index suggests where there is more potential for improving adoption of adaptation strategies in Africa. The sensitivity analysis conducted to test the weighting schemes and component values show that our composite index is moderately robust and seems to be particularly appropriate to estimating regional adoption of farm-level adaptation strategies to climate change. Finally, as adaptation policies planned on global scales will ultimately be implemented on a local and regional basis, the results of this research can be used to develop bottom-up approaches for the benefit of smallholder farmers to climate change.

Acknowledgments We acknowledge the financial support of the European Commission Animal Change project (contract no. KBBE-266018) (<http://www.animalchange.eu>).

Appendix A

Table 3 Details of the 42 case studies that assess factors that influence farm-level adoption of climate change adaptation strategies in Africa through econometric regressions

Author(s) (Year)	Study area	Sample size	Econometric approach	Adaptation strategies as dependent variables
Abdulai et al. (2011)	Ghana	202	Probit	Periphery technique; sieving technology; watering can with shower outlet for transporting water; and close watering techniques when applying irrigation water
Abebew and Haile (2013)	Ethiopia	965	Logit	Cooperative membership
Abebe et al. (2013)	Ethiopia	8000	Probit	Improved varieties of potato (<i>Solanum tuberosum</i> L.)
Adesina and Baidu-Forson (1995)	Guinea	110	Tobit	Improved varieties of rice (<i>Oryza Sativa</i> L. X <i>Oryza Glaberrima</i> Steud.)
Adesina and Baidu-Forson (1995)	Burkina Faso	57	Tobit	Improved varieties of sorghum (<i>Sorghum bicolor</i> (L.) Moench)
Adesina and Chianu (2002)	Nigeria	223	Logit	Introduction of alley farming; modification of the pruning frequency and fallow periods
Adesina et al. (2000)	Cameroon	156	Logit	Adoption of alley farming and its variants
Arslan et al. (2014)	Zambia	8208	Probit	Minimum soil disturbance and crop rotation

Table 3 (continued)

Author(s) (Year)	Study area	Sample size	Econometric approach	Adaptation strategies as dependent variables
Asfaw and Admassie (2004)	Ethiopia	na	Logit	Use of chemical fertiliser input and fertiliser
Baidu-Forson (1999)	Niger	114	Tobit	Improved soil and water management technology
Bryan et al. (2009)	South Africa and Ethiopia	1783	Probit	Farmers' decisions to adapt to perceived climate change
Bryan et al. (2013)	Kenya	657	Logit	Adaptation; change variety; change type; change planting dates; plant trees; destocking; change feeds; change fertiliser; soil and water conservation
Cofie et al. (2010)	Ghana	60	Probit	Excreta use in agriculture
Croppenstedt et al. (2003)	Ethiopia	4100	Tobit	Fertiliser demand
De Groote et al. (2013)	Ethiopia	360	Multinomial logit	Improved varieties; and high biomass varieties of maize (<i>Zea mays</i> L.)
Deressa et al. (2009)	Ethiopia	803	Multinomial logit	Soil conservation; crop varieties; planting trees; changing planting date; irrigation
Di Falco et al. (2011)	Ethiopia	2807	Ordinary least squares	Adoption of adaptation strategies in general
Fischer and Qaim (2012)	Kenya	444	Probit	Group membership
Fisher and Kandiwa (2014)	Malawi	11,051	Logit	Adoption of modern maize seed (<i>Zea mays</i> L.)
Gbetibouo (2009)	South Africa	794	Multinomial logit	Portfolio diversification; irrigation; changed planting dates; changed amount of land; livestock feed supplements; other
Gebrehiwot and van der Veen (2013)	Ethiopia	400	Multinomial logit	Crop diversification; soil conservation; planting trees; changing planting date; irrigation
Giné and Yang (2009)	Malawi	800	Ordinary least squares	Take-up of loan for hybrid seeds
Hassan and Nhemachena (2008)	11 African countries	7327	Multinomial logit	Multiple crops under irrigation; mono crop-livestock under irrigation; multiple crop-livestock under irrigation
Kassie et al. (2013)	Tanzania	681	Probit	Conservation tillage; soil and water conservation; legume intercrop; animal manure; chemical fertiliser; improved seeds; legume crop rotation
Kijima (2011)	Uganda	347	Probit	Improved variety of rice (<i>Oryza Sativa</i> L. X <i>Oryza Glaberrima</i> Steud.)

Table 3 (continued)

Author(s) (Year)	Study area	Sample size	Econometric approach	Adaptation strategies as dependent variables
Lunduka et al. (2012)	Malawi	171	Tobit	Improved hybrid varieties and open pollinated varieties of maize (<i>Zea mays</i> L.)
Marenya and Barrett (2007)	Kenya	123	Probit	Stover lines; agroforestry; manure; inorganic fertilisers
Oben Tabi et al. (2012)	Ghana	74	Multinomial logit	Water control practice; varying planting date; choice of variety; use herbicide and fertiliser
Okoye (1998)	Nigeria	125	Ordinary least squares	Recommended erosion control practices
Oyekale and Idjesa (2009)	Nigeria	150	Probit model	Improved seed varieties
Savadogo et al. (1998)	Burkina Faso	150	Probit	Adoption of animal traction
Savadogo et al. (1998)	Burkina Faso	230	Probit	Adoption of animal traction (Sudano-Sahelian)
Shiferaw and Holden (1998)	Ethiopia	452	Ordinal logit	Use of conservation practices
Sidibé (2005)	Burkina Faso	230	Probit	Adoption of zaï technique and stone strips
Silvestri et al. (2012)	Kenya	640	Logit	Adaptation; destocking; change feeds; change breed; move animals
Somda et al. (2002)	Burkina Faso	57	Logit	Adoption of compost
Somda et al. (2002)	Burkina Faso	69	Logit	Adoption of compost
Thangata and Alavalapati (2003)	Malawi	49	Logit	Uptake of new technologies
Thuo et al. (2011)	Senegal	502	Probit	Adoption of intense agriculture
Wubeneh and Sanders (2006)	Ethiopia	90	Tobit	Improved varieties and inorganic fertiliser
Yegbemey et al. (2013)	Benin	308	Probit	Crops diversification; farming calendar adjustments; land use strategies and other strategies
Zander et al. (2013)	Kenya	149	Multinomial logit	Improved animal husbandry practice; and improved animal breeding strategies

References

- Abdulai A, Owusu V, Bakang JEA (2011) Adoption of safer irrigation technologies and cropping patterns: evidence from southern Ghana. *Ecol Econ* 70(7):1415–1423
- Abebaw D, Haile MG (2013) The impact of cooperatives on agricultural technology adoption: empirical evidence from Ethiopia. *Food Policy* 38:82–91
- Abebe GK, Bijman J, Pascucci S, Omta O (2013) Adoption of improved potato varieties in Ethiopia: the role of agricultural knowledge and innovation system and smallholder farmers' quality assessment. *Agric Syst* 122: 22–32

- Adesina AA, Baidu-Forson J (1995) Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. *Agric Econ* 13:1–9
- Adesina AA, Chianu J (2002) Determinants of farmers' adoption and adaptation of alley farming technology in Nigeria. *Agrofor Syst* 55:99–112
- Adesina AA, Mbilal D, Nkamleu GB, Endamana D (2000) Econometric analysis of the determinants of adoption of alley farming by farmers in the forest zone of southwest Cameroon. *Agric Ecosyst Environ* 80(3):255–265
- Africa Adaptation Programme (AAP) (2013) AAP Terminal Report. Available at: <http://www.undp-aap.org/resources/publications/aap-terminal-report>
- Arrow KJ (1963) Social choice and individual values, 2nd edn. Wiley, New York
- Arslan A, McCarthy N, Lipper L, Asfaw S, Cattaneo A (2014) Adoption and intensity of adoption of conservation farming practices in Zambia. *Agric Ecosyst Environ* 187:72–86
- Asfaw A, Admassie A (2004) The role of education on the adoption of chemical fertiliser under different socioeconomic environments in Ethiopia. *Agric Econ* 30(3):215–228
- Baidu-Forson J (1999) Factors influencing adoption of land-enhancing technology in the Sahel: lessons from a case study in Niger. *Agric Econ* 20(3):231–239
- Barnett J, Adger WN (2007) Climate change, human security and violent conflict. *Political Geography* 26:639–655
- Baumgart-Getz A, Prokopy LS, Floress K (2012) Why farmers adopt best management practice in the United States: a meta-analysis of the adoption literature. *J Environ Manag* 96:17–25
- Beddington J, Asaduzzaman M, Clark M, Fernández A, Guillou M, Jahn M, Erda L, Mamo T, Van Bo N, Nobre CA, Scholes R, Sharma R, Wakhungu J (2012) Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available at: www.ccafs.cgiar.org/commission
- Brooks N, Adger WN, Kelly PM (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Glob Environ Chang* 15:151–163
- Bryan E, Deressa TT, Gbetibouo GA, Ringler C (2009) Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environ Sci Pol* 12(4):413–426
- Bryan E, Ringler C, Okoba B, Roncoli C, Silvestri S, Herrero M (2013) Adapting agriculture to climate change in Kenya: household strategies and determinants. *J Environ Manag* 114:26–35
- Chamey JG (1975) Dynamics of deserts and drought in the Sahel. *Q J R Meteorol Soc* 101:193–202
- Cofie O, Adeoti A, Nkansah-Boadu F, Awuah E (2010) Farmers perception and economic benefits of excreta use in southern Ghana. *Resour Conserv Recycl* 55(2):161–166
- Croppenstedt A, Demeke M, Meschi MM (2003) Technology adoption in the presence of constraints: the case of fertilizer demand in Ethiopia. *Rev Dev Econ* 7(1):58–70
- De Groote H, Dema G, Sonda GB, Gitonga ZM (2013) Maize for food and feed in east Africa—the farmers' perspective. *Field Crop Res* 153:22–36
- Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M (2009) Determinants of farmers' choice of adaptation methods to climate change in the Nile basin of Ethiopia. *Glob Environ Chang* 19:248–255
- Di Falco S, Veronesi M, Yesuf M (2011) Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *Amer J Agr Econ* 93(3):829–846
- Dixon RK, Smith J, Guill S (2003) Life on the edge: vulnerability and adaptation of African ecosystems to global climate change. *Mitig Adapt Strateg Glob Chang* 8:93–113
- Downing TE, Ringius L, Hulme M, Waughray D (1997) Adapting to climate change in Africa. *Mitig Adapt Strateg Glob Chang* 2:19–44
- Fischer E, Qaim M (2012) Linking smallholders to markets: determinants and impacts of farmer collective action in Kenya. *World Dev* 40(6):1255–1268
- Fischer G, Shah M, Tubiello FN, van Velhuizen H (2005) Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. *Phil Trans R Soc B* 360:2067–2083
- Fisher M, Kandiwa V (2014) Can agricultural input subsidies reduce the gender gap in modern maize adoption? Evidence from Malawi. *Food Policy* 45:101–111
- García de Jalón S, Iglesias A, Quiroga S, Bardaji I (2013) Exploring public support for climate change adaptation policies in the Mediterranean region: a case study in southern Spain. *Environ Sci Pol* 29:1–11
- Gbetibouo GA (2009) Understanding farmers' perceptions and adaptations to climate change and variability: the case of the Limpopo Basin, South Africa. IFPRI Discussion Paper 00849. International Food Policy Research Institute (IFPRI), Washington, DC, 52 pp
- Gebrehiwot T, van der Veen A (2013) Farm level adaptation to climate change: the case of farmer's in the Ethiopian highlands. *J Environ Manag* 52:29–44
- Giannini A, Biasutti M, Verstraete MM (2008) A climate model-based review of drought in the Sahel: desertification, the re-greening and climate change. *Glob Planet Chang* 64:119–128

- Giné X, Yang D (2009) Insurance, credit, and technology adoption: field experimental evidence from Malawi. *J Dev Econ* 89(1):1–11
- Hassan R, Nhemachena C (2008) Determinants of African farmers' strategies for adapting to climate change: multinomial choice analysis. *AfJARE* 2(1):83–104
- Intergovernmental Panel on Climate Change (IPCC) (2014) Summary for policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
- International Fund for Agricultural Development (IFAD) (2013) Smallholders, food security, and the environment. Available at: http://www.unep.org/pdf/SmallholderReport_WEB.pdf
- Kassie M, Jaleta M, Shiferaw B, Mmbando F, Mekuria M (2013) Adoption of interrelated sustainable agricultural practices in smallholder systems: evidence from rural Tanzania. *Technol Forecast Soc Chang* 80(3):525–540
- Kijima Y (2011) An inquiry into constraints on a green revolution in Sub-Saharan Africa: the case of NERICA rice in Uganda. *World Dev* 39(1):77–86
- Kiome RM, Stocking M (1995) Rationality of farmer perception of soil erosion: the effectiveness of soil conservation in semi-arid Kenya. *Glob Environ Chang* 5(4):281–295
- Knowler D, Bradshaw B (2007) Farmers' adoption of conservation agriculture: a review and synthesis of recent research. *Food Policy* 32:25–48
- Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL (2008) Prioritizing climate change adaptation needs for food security in 2030. *Science* 319:607–610
- Lunduka R, Fisher M, Snapp S (2012) Could farmer interest in a diversity of seed attributes explain adoption plateaus for modern maize varieties in Malawi? *Food Policy* 37(5):504–510
- Marenya PP, Barrett CB (2007) Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy* 32(4):515–536
- Naumann G, Barbosa B, Garrote L, Iglesias A, Vogt J (2014) Exploring drought vulnerability in Africa: an indicator based analysis to inform early warning systems. *Hydrol Earth Syst Sci* 18:1591–1604
- Ngigi SN (2009) *Climate Change Adaptation Strategies: Water Resources Management Options for Smallholder Farming Systems in Sub-Saharan Africa*. The MDG Centre for East and Southern Africa, The Earth Institute at Columbia University, New York. 189 pp
- Nhemachena C, Hassan R (2007) Micro-Level Analysis of Farmers' Adaptation to Climate Change in Southern Africa. IFPRI Discussion Paper 00714. Environment and Production Technology Division. Available at: <http://www.ifpri.org/sites/default/files/pubs/pubs/dp/ifpridp00714.pdf>
- Niang I and Ruppel OC (2014) Chapter 22. Africa. In Field et al. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
- Nielsen JØ, Reenberg A (2010) Cultural barriers to climate change adaptation: a case study from northern Burkina Faso. *Glob Environ Chang* 20:142–152
- Nzuma JM, Waithaka M, Mulwa RM, Kyotalimye M, Nelson G (2010) Strategies for Adapting to Climate Change in Rural Sub-Saharan Africa. A Review of Data Sources, Poverty Reduction Strategy Programs (PRSPs) and National Adaptation Plans for Agriculture (NAPAs) in ASARECA Member Countries. IFPRI Discussion Paper 01013. Environment and Production Technology Division. Available at: <http://www.ifpri.org/publications/results/taxonomy%3A468>
- Oben Tabi F, Adiku SGK, Ofori K, Nhamo N, Omoko M, Atika E, Mayebi A (2012) Perceptions of Rain-Fed Lowland Rice Farmers on Climate Change, Their Vulnerability, and Adaptation Strategies in the Volta Region of Ghana. In: Bolay, J.-C, et al. (eds.), *Technologies and Innovations for Development*, DOI 10.1007/978-2-8178-0268-8_12, Springer, Verlag, France
- OECD (2008) Handbook on constructing composite indicators: methodology and user guide. Available at: <http://www.oecd.org/std/42495745.pdf>
- Okoye CU (1998) Comparative analysis of factors in the adoption of traditional and recommended soil erosion control practices in Nigeria. *Soil Tillage Res* 45(3–4):251–263
- Oyekale AS, Idjese E (2009) Adoption of improved maize seeds and production efficiency in rivers state, Nigeria. *Acad J Plant Sci* 2(1):44–50
- Parry ML, Rosenzweig C, Iglesias A, Livermore M, Fischer G (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Glob Environ Chang* 14:53–67
- Salehyan I (2008) From climate change to conflict? No consensus yet. *J Peace Res* 45(3):315–326
- Savadoogo K, Reardon T, Pietola K (1998) Adoption of improved land use technologies to increase food security in Burkina Faso: relating animal traction, productivity, and non-farm income. *Agric Syst* 58(3):441–464

- Schlenker W, Lobell DB (2010) Robust negative impacts of climate change on African agriculture. *Environ Res Lett* 5:1–8
- Schmidhuber J, Tubiello FN (2007) Global food security under climate change. *Proc Natl Acad Sci* 104(50):19703–19708
- Shiferaw B, Holden ST (1998) Resource degradation and adoption of land conservation technologies in the Ethiopian highlands: a case study in Andit Tid, north Shewa. *Agric Econ* 18(3):233–247
- Sidibé A (2005) Farm-level adoption of soil and water conservation techniques in northern Burkina Faso. *Agric Water Manag* 71(3):211–224
- Silvestri S, Bryan E, Ringler C, Herrero M, Okoba B (2012) Climate change perception and adaptation of agro-pastoral communities in Kenya. *Reg Environ Change* 12:791–802
- Smit B, Skinner MW (2002) Adaptation options in agriculture to climate change: a typology. *Mitig Adapt Strateg Glob Chang* 7:85–114
- Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. *Glob Environ Chang* 16:282–292
- Somda J, Nianogo AJ, Nassa S, Sanou S (2002) Soil fertility management and socio-economic factors in crop-livestock systems in Burkina Faso: a case study of composting technology. *Ecol Econ* 43(2–3):175–183
- Thangata PH, Alavalapati JRR (2003) Agroforestry adoption in southern Malawi: the case of mixed intercropping of *Gliricidia sepium* and maize. *Agric Syst* 78(1):57–71
- Thomton PK, Jones PG, Owiyo T, Kruska RL, Herrero M, Kristjanson P, Notenbaert A, Bekele N, Omolo A (2006) Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development, ILRI, PO Box. 709, Nairobi 00100, Kenya. Pp 171. Available at: http://www.acts.or.ke/dmdocuments/Mapping_Vuln_Africa.pdf
- Thuo M, Bravo-Ureta BE, Hathié I, Obeng-Asiedu P (2011) Adoption of chemical fertilizer by smallholder farmers in the peanut basin of Senegal. *AfJARE* 6(1):1–17
- UNFCCC (United Nations Framework Convention on Climate Change) (2011) Assessing the costs and benefits of adaptation options an overview of approaches. The Nairobi Work Programme on impacts, vulnerability and adaptation to climate change. United Nations Climate Change Secretariat. Bonn, Germany. http://unfccc.int/resource/docs/publications/pub_nwp_costs_benefits_adaptation.pdf
- Vincent K (2004) Creating an index of social vulnerability to climate change for Africa. Tyndall Centre Working Paper No. 56. Norwich, UK. Available at: <http://www.tyndall.ac.uk/sites/default/files/wp56.pdf>
- Wubeneh NG, Sanders JH (2006) Farm-level adoption of sorghum technologies in Tigray, Ethiopia. *Agric Syst* 91(1–2):122–134
- Yegbemey RN, Yabi JA, Tovignan SD, Gantoli G, Kokoye SEH (2013) Farmers' decisions to adapt to climate change under various property rights: a case study of maize farming in northern Benin (West Africa). *Land Use Policy* 34:168–175
- Zander KK, Mwacharo JM, Drucker AG, Garnett ST (2013) Constraints to effective adoption of innovative livestock production technologies in the Rift Valley (Kenya). *J Arid Environ* 96:9–18