Greenhouse Gas Observation
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Report on needs and gaps in Africa in terms of data, knowledge and RI with recommendations for a joint EU-Africa Research & STI agenda on GHG observations focusing on land use and land use change under a changing climate

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List of Acronyms

AEW	African Easterly Waves
AMMA	African Monsoon Multidisciplinary Analysis
ANAM-BF	Agence Nationale de la météorologie - Burkina Faso
APSIM	The Agricultural Production Systems Simulator
ARPEGE	Action de Recherche Petite Echelle Grande Echelle
C	Carbon
CAMS-OPI	Climate Anomaly Monitoring System (CAMS) -Precipitation Index (OPI)
CAR	Conditional Auto-Regression
CGIAR	Consultative Group on International Agricultural Research
CH_4	Methane
CO_2	Carbon dioxide
CMCC	Foundation Euro-Mediterranean Center on Climate Change
CMA	China Meteorological Administration
CMAP	Center Merged Analysis of Precipitation
CMORPH	The Climate Prediction Center morphing method
CPTEC	Centro de Previsão Tempo e Estudos Climáticos
CRU	Climatic Research Unit
CSA	Climate Smart Agriculture
DSSAT	The Decision Support System for Agrotechnology Transfer
ECMWF	European Centre for Medium-Range Weather Forecasts
EnKF	Ensemble Kalman Filter
EO	Earth Observation
EPIC	Economics and Policy Innovations for Climate-Smart Agriculture
ERA	Re-Analysis
EU	European Union
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FEWS	Farmine Early Warning System (RFE1.0 and RFE2.0)
FLW	Food Loss and Waste
GFS	Global Forecast System
GHGs	Greenhouse Gas
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
IFS	Integrated Forecast System
ITCZ	The intertropical convergence zone
JMA	Japan Meteorological Agency
KMA	Korea Meteorological Administration
LEDS	Low emission development strategies
LUC	Land Use Change
GPS	Global Positioning System
GWP	Global Warming Potential
GWR	Geographical Weighted Regression
IPCC	Intergovernmental Panel on Climate Change
LWNN	Land Water Nutrient Nexus
MF	Météo-France
MSC	Meteorological Service of Canada
MSPs	Multi-stakeholder partnerships

NAMAs	Nationally Appropriate Mitigation Actions
NARS	National Agricultural Research Systems
NCEP	National Centers for Environmental Prediction
NGO	Non-Governmental Organization
N_2O	Nitrous oxide
NWP	Numerical Weather Prediction
OSEs	Observing System Experiments
PRECL	Precipitation Reconstruction over Land
PWV	Precipitable Water Vapour
RIs	Research Infrastructures
SAS	Sub-Saharan Africa
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SEACRIFOG	Supporting EU-African Cooperation on Research Infrastructures for Food Security and Greenhouse Gas Observations
SES	Social–Ecological Systems
SIEREM	HydroSciences Montpellier, France
SOC	Soil Organic Carbon
TARCAT	Time-series dataset
TAMSAT	Tropical Applicatons of Meteo-rology using SATellite (TAMSAT)
TRMM	Tropical Rainfall Measuring Mission (TRMM 3B42 version 6, 7)
UDEL	University of Delaware
UKMO	United Kingdom Met Office
UM	Unified Model
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
VA	Vulnerability Assessment
WAM	West African Monsoon
WASCAL	West African Science Service Center on Climate Change and Adapted Land Use,
WOFOST	World Food Studies
WAM	West African Monsoon
WP	Work Package
WRF	Weather Research and Forecasting

Executive summary

Africa has achieved remarkable economic, political and social growth in recent decades but present threat that climate change poses, in terms of natural disasters, recurrent droughts and floods as results of changes in temperatures and rainfall regimes, are primary drivers of vulnerability and food insecurity. "Understanding the impacts of climate change on development priorities in Africa – and adapting economies, societies, natural resource management practices, energy investments, budgets and policies to its expected and uncertain consequences – is essential in the pursuit of sustainable development and improved climate governance" (UNDP, 2018).

This requires an assessment of what is needed in terms of data, knowledge, capacities and research infrastructures (as long term greenhouse gases (GHG) observational systems). The assessment need to consider both scientific and socio-economical dimensions to support daring, innovative approaches in order to foster low-carbon climate-resilient development across sub-Saharan Africa (SSA) and the rest of the continent.

The Deliverable 1.1 of the SEACRIFOG project, reports about the assessment of needs and gaps in Africa in terms of data, knowledge, capacities and research infrastructures related to GHG observations from land use (particularly agriculture) and land use change under a changing climate. Methodological approaches are described on the basis of activities carried on within different tasks and results are then discussed in order to make considerations and propose recommendations for future steps.

1 INTRODUCTION

African societies face growing global change risks, with rapidly changing patterns of human settlements and intensity of use of ecosystem services. At the same time, climate variability and climate change are intensifying stress on the ecosystems that ensure environmental security, both locally (e.g. ecosystem services), regionally (e.g. sustainable development options) and internationally (e.g. carbon sequestration). Negative consequences of climate change on food security and livelihoods are widely recognized particularly in sub-Saharan Africa (SSA) and especially in rural communities. Sub-Saharan Africa is vulnerable to climate change, as multiple biophysical, political, and socioeconomic stresses interact heightening the region's susceptibility and constraining its adaptive capacity (Connolly-Boutin and Smit, 2016). Climate change will generally decrease yields but humanity needs to produce more food to meet future demand. Agriculture is the core of food security but it is also the major driving force for greenhouse gas emissions, water quality degradation from soil loss and nutrient runoff, and water use. The largest sources of agricultural GHGs are carbon dioxide (CO_2) from tropical deforestation, methane (CH_4) from livestock and rice production, and nitrous oxide (N_2O) from nutrient additions to croplands. Agriculture accounts for 20 to 35% of global GHG emissions (West et al., 2014) and in Africa are among the fastest growing emissions in the world (Valentini et al., 2014).

Approaches that can address this challenge in an integrated and multidisciplinary way are urgently needed in many places in Africa where there is a close relationship between societal well-being and environmental condition, relating for instance to biomass for energy and food production, and hydrological considerations such as water yields.

Policymakers and land-use decision makers are increasingly dependent on knowledge on the state of the environment. Long-term observational systems and research infrastructures have been identified to be indispensable elements of knowledge generation to serve food security, climate change adaptation and mitigation.

The overall task of WP1 is to assess the current status in terms of data, knowledge, capacities and research infrastructures related to GHG observations from land use (particularly agriculture) and land use change under a changing climate in Africa. It relies on users, stakeholders and expert groups' engagement, and on the use of tools like surveys, working meetings, journals' review and others.

Stakeholders' involvement has become a common practice in interdisciplinary research projects (Mielke et al. 2017, Ginige et al., 2018) and in the context of SEACRIFOG it is crucial to ensure that African knowledge is integrated into the project framework. SEACRIFOG project recognizes the important role of stakeholders' engagement and knowledge co-production when designing an adaptive concept for a pan-African observational system of climate parameters and GHG (López-Ballesteros et al., 2018).

This document encompasses a wide range of outcomes and takes stock of the results, relevant to the project itself but functional to stakeholders in order to give an overview and guidelines related to needs and gaps assessed.

2 METHODOLOGICAL APPROACH

2.1 Users and stakeholders engagement

The process of stakeholders engagement and participation is now widely viewed as an essential component of environmental management projects (Holifield and Williams, 2018) and it is crucial in order to enhance the quality of the project through the cooperation between parties and the resulting output of information which interlock in an integration of local and scientific knowledge (Luyet et al. 2012; Reed 2008; Tippett et al. 2007). In line with the growing emphasis on the role of culture in development, local knowledge (defined as including indigenous knowledge, traditional ecological knowledge, local ecological knowledge), has gained prominence in the discussions of climate change. In regions or geographical localities of the world with paucity of scientific data on weather and environmental change observation, indigenous, traditional[1] and local knowledge could fill this gap in information (Codjoe et al., 2013).

Considering the importance of stakeholders involvement and of traditional and local knowledge, feedbacks gathered from different backgrounds and expertise can guarantee an inter-sectoral approach to the main thematic areas with a cross cutting view to solutions. Results from this activity are relevant for all the WP1's tasks (knowledge, data, infrastructures, capacities), being a starting point for wider analysis. WP1 activities regarding stakeholders involvement, entailed the following stages: (i) stakeholder identification and classification; (ii) selection; (iii) engagement; and (iv) co-production of results. The first step of stage (i) was to define the stakeholders' categories with highest relevance in the project: (1) academia, (2) research, (3) infrastructures, (4) farmers, (5) NGOs, (6) UN and international organizations, (7) governmental institutions and (8) private sector.

Secondly, the main topics to be addressed in the dialogue with stakeholders were defined: GHG and climate observation, land use change, food security, climate-smart agriculture, capacity development and links with policy. Then an inventory with more than 100 stakeholders, potentially relevant to the above topics, was compiled via web search and the project partners' networks. With the project consortium having a long history of partnership in Africa, this latter point was proved to be crucial to enable effective and proactive stakeholder engagement.

Finally, all identified stakeholders were classified according to the above categories and topics, as well as their geographical coverage (local, national, regional, global). The key criterion for the stakeholders' selection (stage (ii)) was to balance the above classes in order to ensure equal representation of the different categories.

Additional criteria were: presence of direct contacts within the consortium, stakeholders' responsiveness and gender balance. Further criteria were specifically adopted to facilitate the participation in the stakeholder workshops: joining already planned relevant events and inviting stakeholders preferably from the target geographical region of that event in order to minimize travel costs while maximizing local expertise. The stakeholders' engagement and results coproduction stages (iii and iv) started with the organization of three regional Stakeholders Consultation

[1] The distinction between traditional knowledge and indigenous knowledge relates to the holders rather than the knowledge *per se*. Traditional knowledge is a broader category that includes indigenous knowledge as a type of traditional knowledge held by indigenous communities (Brush, 2005).

Workshops, held in Nairobi (Kenya—East Africa, 31 May 2017), Sunyani (Ghana—West Africa, 16 June 2017) and Lusaka (Zambia—South Africa, 18 April 2018). In total, 73 participants from 33 organizations attended the three stakeholder's workshops.

The world café approach (Brown and Isaacs 2005, Palacios-Agundez et al 2013) was adopted to ensure a participative stakeholder dialogue and capacity knowledge co-production. The World Café is a structured conversational process intended to facilitate discussion, initially in small groups and then linking ideas within a larger group to access the collective intelligence or collective wisdom in the room (Brown and Isaacs, 2005). Organizers of a World Café formulate questions before an event, related to its goals, which are discussed by participants as they move between a series of tables. The name of the process relates to atmosphere seeks to create, as a means to facilitate conversation. As well as speaking and listening, individuals are encouraged to write on a paper or flipchart, so when people change tables they can see what previous members have expressed in their own words and images through mind maps[2].

During the World Café, the participants shared their knowledge about:

1) Land use change implications on food security,

2) GHG observations, carbon stocks and climate change mitigation,

3) Clime-smart agriculture in Africa,

4) Capacity Development.

Cross-cutting issues were discussed within the thematic groups included:

-*Research infrastructures* (current RI on the thematic groups topics, leading institutes, available research services – national, international platforms, what´s lacking, what´s needed to be developed, etc.)

-*Data and knowledge needs and gaps* (what data are available respect to which data are used/needed, what are the knowledge gaps, data policy - access to data)
-*User needs* (from perspectives of particular stakeholders – e.g. scientist, practitioners, farmers)
-*Capacity-building* (personal, institutional capacity and political willingness, outreach of scientific outcomes, good practice etc.)
-*Barriers and opportunities* (that limit the use of available data, etc.)

The engagement and participation of stakeholders belonging to various key categories such as researchers, decision makers, farmers, NGOs, at national and regional level from Africa and EU, enable us to gather information useful to the assessment of knowledge and data needs and gaps as well as infrastructural and capacity needs and gaps at different levels.

[2] The mind map is an expression of radiant thinking. It is used to represent graphically words, ideas, tasks, or other items linked to and arranged around a central key word or idea. Mind maps contain information, in the nodes, in the linked objects and in their structure. (Source: http://eprints.rclis.org/15842/1/04.Siochos.pdf).

Figure1: 1st SEACRIFOG Stakeholder Consultation Workshops, Nairobi, Kenya

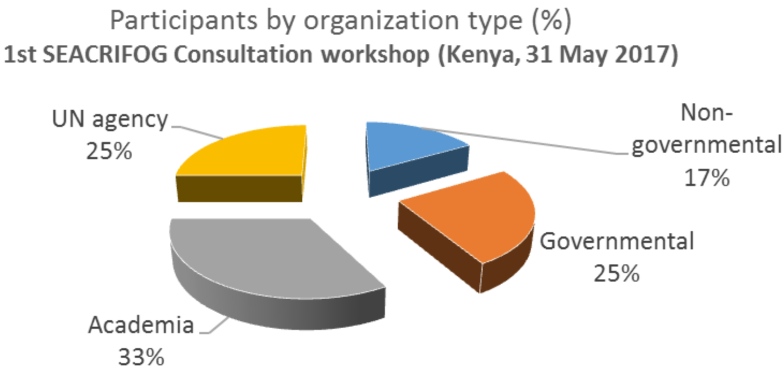

Figure 2: SEACRIFOG Stakeholder Consultation Workshop participants by organization type (Kenya, 31 May 2017)[3].

Figure 3: Graphical summary (i.e. mind maps) of world café discussions

[3] *For detailed stakeholder composition see Annex 1*

Figure 4: 2nd SEACRIFOG Stakeholder Consultation Workshops, Sunyani, Ghana

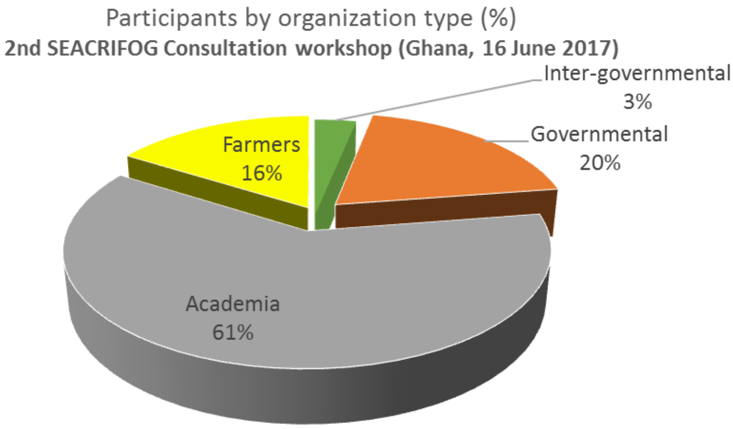

Figure 5: SEACRIFOG Stakeholder Consultation Workshop participants by organization type (Ghana, 16 June 2017)[4].

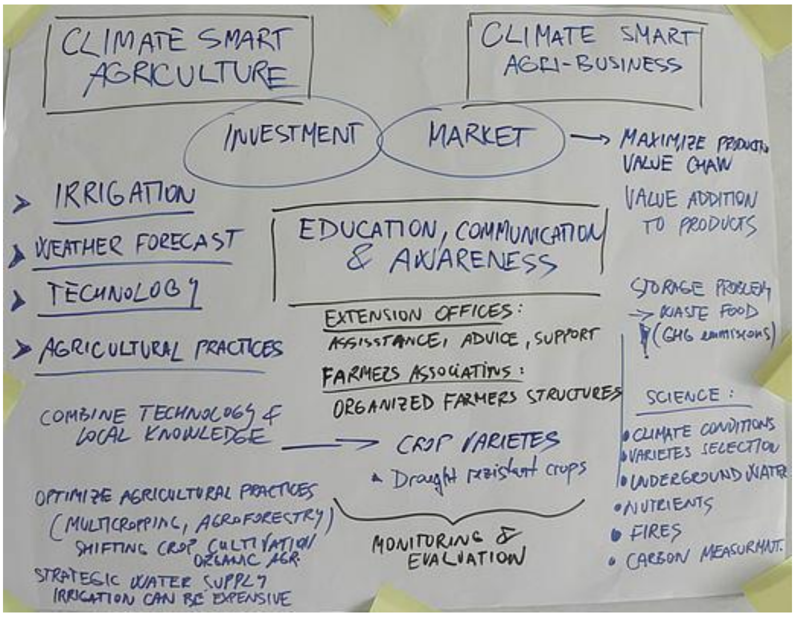

Figure 6: Graphical summary of world café discussions

[4] For detailed stakeholder composition see Annex 1

Figure 7: 3rd SEACRIFOG Stakeholder Consultation Workshops, Lusaka, Zambia (author: Meshach Shikabeta, Zambia)

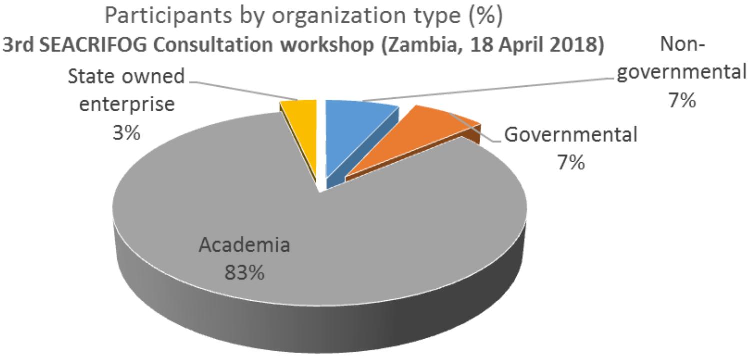

Figure 8: SEACRIFOG Stakeholder Consultation Workshop participants by organization type (Zambia, 18 April 2018)[5].

Figure 9: Graphical summary of world café discussions

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[5] For detailed stakeholder composition see Annex 1

2.2 Knowledge needs and gaps

The benefits of integrating diverse types of knowledge systems are widely recognized. Integrating stakeholder knowledge is useful to add flexibility and to lead to more resilient outcomes in social–ecological systems (SES) because knowledge diversity reduces rigidity, represents multiple perspectives, and promotes adaptability in decision-making. A knowledge system refers to a coherent set of mental constructs, cognitions, and practices held by individuals within a particular community. Knowledge integration is commonly promoted including the public in decision making and allows the local context and behaviors of individuals to be better understood so that uncertainty can be reduced. Knowledge systems are coarsely defined as two main categories: local knowledge and scientific knowledge (Gray et al., 2012).

Local knowledge reflects individual experiences (Fazey et al., 2008) or non-expert or localized information (Jones, 1995). Local knowledge includes traditional, indigenous and lay knowledge, each describing a particular point on a continuum of knowledge mediated by personal or cultural experiences.

Scientific knowledge refers to knowledge created by more systematic means. Scientific knowledge utilizes agreed principles and a process of study, including reliability and validity to generate new information (Turnbull, 1997; Gunderson and Holling, 2002).

Additionally, it is likely that all stakeholders hold varying degrees of both local knowledge and scientific knowledge concurrently. Characterizing the differences between knowledge systems, however, is not easy. These categories alone do little to explain how or why individuals or groups may anticipate environmental or social change (Gray et al., 2012).

Worldwide, the complexity of environmental problems mainly related to climate change and their increasing negative effects and damaging impacts on social and ecological systems have heightened the stakes for research that both increases understanding and informs potential solutions. Managing climate-change-related risks, requires knowledge-intensive adaptive management and policy-making actively informed by scientific knowledge, especially climate science. However, potentially useful climate information often goes unused. Despite both the considerable amount of climate change research made available in the past thirty years and evidence that decision-makers at the local and resource management level (for example, agriculture, water, disaster response and urban planning) are actively seeking to increase their climate information uptake, there is a persistent gap between knowledge production and use. This reflects the distinction between useful and usable information which underlines the different ways that producers and users perceive scientific information (Lemos et al., 2012).

Within WP1, local knowledge needs and gaps assessment was mainly performed through the stakeholder consultation workshops (described in the previous section 2.1) while the assessment of knowledge needs and gaps from a scientific point of view was achieved through both the consultation workshops and bibliographical research at different levels.

In particular we have addressed knowledge needs and gaps related to the following topics:

2.2.1 Uncertainties of scientific models on crop yield, on observed precipitation products and weather forecasting.

In the framework of WP1, different activities were carried on, part of them consisted in a deep analysis of literature focused on food and nutrition security, climate change adaptation and mitigation strategies, and greenhouse gas observation related to the climate change issues. Concerning the knowledge gaps and user needs, the approach consisted in producing a combined mapping and clustering of the most frequently cited publications that appeared in the below mentioned thematic areas for the period 2006-2016. Term maps based on bibliometric, climate change research in Africa as published in Crossref database were generated. The keys thematic areas that were identified as essential for the concern matter are:

- ✓ Climate change adaptation strategies
- ✓ Climate change mitigation strategies
- ✓ The cost-benefit analysis of adaptation strategies
- ✓ Crop yield models and uncertainty
- ✓ Precipitation products and weather forecasting models
- ✓ Food and nutrition security in Africa –and models?
- ✓ Food Security Early Warning Systems (FS-EWS)
- ✓ Regional allometric models in Africa for carbon assessments
- ✓ GHGs emissions models in Africa and uncertainty

A priori relevant are all publications listed in Crossref database in the fields mentioned in the Table 1.

Sub-themes	**Number of collected documents from Crossref database (if available)**	**Number of clusters**	**Number of most important selected / searched documents**
User needs and knowledge gaps on climate change adaptation strategies	2346	07	39
User needs and knowledge gaps on climate change mitigation strategies	756	08	21
Uncertainties of scientific models on crop yield	-	-	42
Uncertainties in observed precipitation products and weather forecasting models	-	-	12

Table 1 : Key thematic area

However, the analysis is limited to the most recent years (2006 to 2016). In fact, very recent papers have less chance to be cited. To explore the topics addressed in different journals with respect to their impact, their overlap, and potential gaps in the concerned topics, the "Software survey: VOSviewer, a computer program (Eck and Waltman, 2018) as proposed in the project proposal was used. This software generates term maps from bibliographic data exported from Crossref. The generated maps revealed food security, climate change adaptation and mitigation strategies, crops yield models, early warning systems, GHGs fluxes etc. The Cross-ref database were compiled with about 3200 document for bibliographic coupling analysis. About 120 documents and published papers from these documents were selected and downloaded till to date, based on the above mentioned keys thematic areas. The results were fulfilled regarding climate change adaptation and mitigation and the cost benefit analysis of adaptation.

In the case the thematic area does not belong to the Crossref database, simple web search was done till we get the maximum documents which are suitable to our research. In the case of uncertainty in crop yield model for example in addition to the literature review, questionnaire was designed and submitted to identify potential experts who published in the concerned thematic area. Questionnaire were design for thematic area to confirm the relevance of information retrieved from literature review. The questionnaire regarding crop yield models and uncertainty contained information about uncertainty on crop yield and related mandatory variables that could be a source of uncertainty. The potential authors were identified based on the published papers on crop yield models. The questionnaire was addressed to these authors. Analysis in the field of crop yield models and uncertainty, and in precipitation products and weather forecasting models based on African Monsoon Multidisciplinary Analysis (AMMA) results were performed. The results were presented based on the cluster obtained from each defined sub-theme (Tab.1). The Figure 10 shows various steps used to obtain the keys findings of our research.

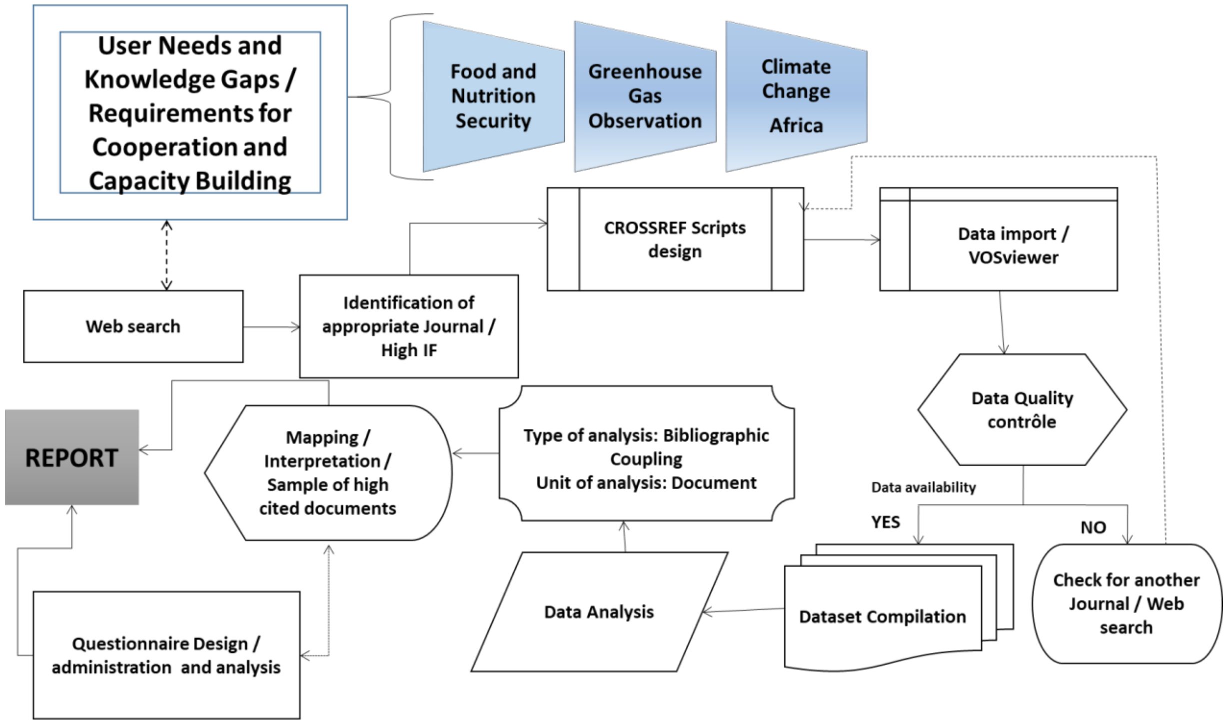


Fig. 10: Flowchart showing the methodological approach

2.2.2 Land-water-nutrient nexus to enhance food security and mitigate greenhouse gas emission in smallholder crop farming systems in sub-Saharan Africa

To enhance food security, smallholder farmers in SSA, as occurring in other agricultural regions of the world, generally adopt a single approach rather than an integration of multiple approaches (e.g., Sheahan and Barrett, 2017). To achieve the goal of ensuring food security and GHG mitigation in smallholder crop farming in SSA, it is necessary to consider different approaches comprehensively (Sheahan and Barrett, 2017; Zougmoré et al., 2014; Branca et al., 2013) since adopting a single approach cannot properly manage the complexity of food security and GHG mitigation under a changing climate. On the other hand, the adoption of different approaches can create positive synergetic effects beyond the additive effect of each approach (Zougmoré et al., 2014; Branca et al., 2013; Sanz-Cobena et al., 2017). Even so, due to the lack of on-site data, further efforts including research and field demonstration identifying optimal combinations of different approaches are critically required (Sheahan and Barrett, 2017; Zougmoré et al., 2014; Branca et al., 2013). To increase yield productivity and potentially ensure food security, smallholder farmers in SSA have been commonly practicing expansion of agricultural lands, development of water harvesting and irrigation techniques, and increasing cropping intensity and fertilizer use. These practices may result in changing carbon stocks and GHG emission, potentially creating trade-offs between food security and GHG mitigation in SSA. Agricultural land expansion, at the expense of forests, is the most dominant source of GHG emissions in SSA. Water harvesting and irrigation can increase soil organic carbon (SOC) since they can enhance the crop biomass and consequently result in higher input of organic matter into soils. However, at the same time they can trigger GHG emissions due to enhancing soil microbial activities and the rewetting effect in dry soil. Increasing cropping intensity can enhance decomposition of soil organic matter, releasing carbon dioxide (CO_2), and increasing nitrogen (N) fertilizer use can result in increasing nitrous oxide (N_2O) emissions. The identification of current land management practices to enhance food security, the assessment of how the practices can affect greenhouse gas emissions, and the assessment of measures that can enhance food security and mitigate GHG emissions in smallholder crop farming systems in SSA was performed within the analysis of *"Land-water-nutrient nexus to enhance food security and mitigate greenhouse gas emission in smallholder crop farming systems in sub-Saharan Africa"*.

2.3 Data needs and gaps

Africa's development agenda is strictly related to policy, planning and decision-making process which relies on available information. The impact of decisions made, depends on the quality of needed data that is the building blocks of information. The capacity to collect solid, timely and reliable data is vital but it is a substantial issue in Africa. If allocation of resources are guided by statistical evidence, there is room for sustainable development because evidence-based decision making will determine where donor funds are needed the most for development, where governments need to channel their resources to improve the social welfare, what policies are needed to bolster agricultural productivity and how rural development programs are impacting communities in the region. Good quality data needs to be accurate to ensure policies attain their intended impact on societies (Stanley, 2018). Despite both the significant amount of climate change research made available in the past thirty years and evidence that decision-makers at the local and resource management level (for example, agriculture, water, disaster response and urban planning) are actively seeking to increase their climate information uptake, there is still a gap between knowledge production and use since the information considered useful by scientists are often not usable by final users (Lemos et al., 2012). Although the projection of serious climate-related challenges in Africa, accordingly to the socio-economic and environmental scenarios, there is a lack of representative, systematic and harmonized ground observations across the continent which hampers the assessment of the relative role of Africa in the current global change paradigm (López-Ballesteros et al., 2018). The increasing food demand due to population growth in Africa, intensification of agricultural production with additions of more inputs of synthetic fertilizer, and expanding agricultural lands are the major factors that cause this rapid growth of emissions but data limitations in Africa increase uncertainty in the results and prevent detailed analysis that is essential for both domestic and international planning for mitigation. The emissions per capita and per unit of economy show that the least developed countries have the highest intensities, indicating the heavy reliance of the citizens' livelihoods on carbon intensive agriculture. Most national GHG reports and communications to the UNFCCC do not provide sufficient details regarding agricultural emissions in the continent (Tongwane and Moeletsi, 2018) so mitigation potentials remain uncertain as most have been estimated through highly aggregated data (Vermeulen et al., 2012). At both local and national levels, greenhouse gas budgets for specific farm practices, foods and landscapes are often unavailable, especially in low-income countries. Full accounting of GHGs across all land uses is necessary to account for leakage and to monitor the impacts of intensification. Measurement technologies are well known, but monitoring of indicators and life-cycle analysis can be expensive and interactions among farm practices difficult to assess (Vermeulen et al., 2012). This lack of representative, systematic and harmonized greenhouse gas (GHG) observations covers the variety of natural and human-altered biomes that occur in Africa and impedes the long-term assessment of the drivers of climate change, in addition to their impacts and feedback loops at the continental scale, but also limits our understanding of the contribution of the African continent to the global carbon (C) cycle. Given the current and projected transformation of socio-economic conditions in Africa (i.e. the increasing trend of urbanization and population growth) and the adverse impacts of climate change, the development of a GHG research infrastructure (RI) is needed to support the design of suitable mitigation and adaptation strategies required to assure food, fuel, nutrition and economic security for the African population (López-Ballesteros et al., 2018). According to López-Ballesteros et al. (2018), the assessment of the African GHG observation networks provides significant evidence of the gaps in the observational capacity in Africa. Standardized in situ observations can contribute to the reduction of uncertainty associated with African and global GHG budgets. The resulting data can be crucial to support the design of early-warning systems as well as suitable mitigation and adaptation strategies that would contribute to food, nutrition and economic security for African populations, which in turn could provide financial incentives in the context of the global Environmental Carbon Market.

Thus, it is evident that developing an informed and effective plan of GHG emission mitigation it is essential for public policy planning and it relies on national greenhouse gas (GHG) inventories.

Aside the lack of GHG observation research infrastructures, data are needed to feed the inventories which provide essential information and enhance environmental integrity in planning and development of GHG mitigation policy, such as baseline and mitigation scenarios for nationally appropriate mitigation actions (NAMAs), and low emission development strategies (LEDS). Furthermore, GHG inventories track the trends in emissions after actions and strategies are implemented, and can be used to assess the outcomes. National GHG inventories are an essential component of climate change policy development and negotiations among party countries to the United Nations Framework Convention on Climate Change (UNFCCC) (Ogle et al., 2013). African countries belong to the Non-Annex I parties[6] of the UNFCCC, who report their national greenhouse gas (GHG) inventories with lower periodicity compared to the Annex I parties[7] and GHG emission estimates are often biased by using Intergovernmental Panel on Climate Change (IPCC) Tier 1 (simpler GHG accounting methodology with adoption of default factors). While most African nations published national GHG emission inventories in 1994 and 2000, knowledge gaps still exist at the continental scale with reports currently absent for four of the fifty-four African countries (López-Ballesteros et al., 2018). Emissions and removals in terms of GHGs (carbon dioxide, methane and nitrous oxide) are reported by sectors (energy, industry, waste, agriculture, land use change and forestry) (UNFCCC, 2018) but the low periodicity added to data inconsistencies, uncertainties and various sources of errors, make those meta data, really challenging to be aggregated. Nonetheless, National Communications could be a good starting point for a comprehensive view of African emissions although it persists the big challenge of the uncertainties and robustness of the data. The assessment of current situation in terms of knowledge and data availability as well as capacities on field, could give a boost in improving the understanding of the relationships among climate, food, and livelihoods that is more than a scientific imperative—it is also necessary to help guide practical initiatives, such as policies, programs, and actions (including climate change adaptation), intended to sustain or improve the livelihoods and food security of people in sub-Saharan Africa as the climate continues to change. Initiatives - and we dare to say also studies -that do not recognize these interrelationships run the risk of being ineffective (Connolly-Boutin and Smit, 2016). Within WP1 activities, GHG emissions has been accounted for the main emission sectors (agriculture, energy, industry, waste and land use change and forestry) accordingly to UNFCCC national communications available data. The dataset has been normalized in terms of year of reference (2000) and in terms of Global Warming Potential (GWP) in consideration of what formally requested in decision 17/CP8, par. 20, "Non-Annex I Parties wishing to report on aggregated GHG emissions and removals expressed in CO_2 equivalents should

[6] *Non-Annex I Parties* are mostly developing countries. Certain groups of developing countries are recognized by the Convention as being especially vulnerable to the adverse impacts of climate change, including countries with low-lying coastal areas and those prone to desertification and drought. Others (such as countries that rely heavily on income from fossil fuel production and commerce) feel more vulnerable to the potential economic impacts of climate change response measures. The Convention emphasizes activities that promise to answer the special needs and concerns of these vulnerable countries, such as investment, insurance and technology transfer. (Source: https://unfccc.int/parties-observers)

[7] *Annex I Parties* include the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.
(Source: https://unfccc.int/parties-observers)

use the GWP provided by the IPCC in its Second Assessment Report ("1995 IPCC GWP Values") based on the effects of GHGs over a 100-year time horizon".

Essential variables from terrestrial observation systems

Accordingly to the results from Del.4.2, terrestrial in situ datasets and products are relatively scarce for Africa, particularly those that are long-term and continuous in nature. The spatial coverage of in situ observations is thin and patchy. There is a need to cover the different biomes and ecosystems more homogeneously, particularly those areas with potentially important GHG source/sink dynamics and rather low human disturbance. While the sub-regions of Central and East Africa appear to be severely understudied in general, there are numerous ecoregions which appear to be understudied. Some of the essential variables identified in line with SEACRIFOG are already largely covered by remote sensing technology or can be expected to be observable from space in the near to mid future. Given the global, periodic, quasi non-invasive and standardized character of satellite remote sensing measures, re-motely sensed variables can be considered as 'low hanging fruits', meaning they are easier to generate than non-remotely sensed variables, which have to be assembled from disparate and local sources of information. The (largely) remotely sensed essential variables include active fire and burnt area, surface albedo and net radiation, cloud cover, extent of inland waters, Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), land cover, ocean color (and ocean chlorophyll content), sea surface temperature, precipitation and wind at surface. Accordingly, these variables have a rather low priority with regards to SEACRIFOG's observation RI design, since it is expected that they will require little effort in terms of additional in situ observations as compared to other variables in order to be measured at sufficient accuracy.

Integrating all its work on interrelated tasks, SASSCAL specifically developed the 'SEACRIFOG Collaborative Inventory Tool' (http://seacrifog-tool.sasscal.org/), which is hosted on SASSCAL's webserver. This web tool is used to systematically capture and contextualize information and metadata on variables, existing observation infrastructure and corresponding data products. A comprehensive inventory of the latter is work in progress. For each variable to be observed by the RI network designed under SEACRIFOG, existing data products are identified and assessed against their spatial and temporal coverage as well as quality. This assessment of existing data products will reveal the major data needs and gaps in the context of SEACRIFOG.

2.4 Infrastructural needs and gaps

A pan-Africa research infrastructure to monitor key variables related to climate change and mitigation and adaption is currently lacking. Moreover, the observations need to be collected on a long-term period to fully understand trends and dynamics of the monitored systems.

The identification of the RIs' nature and status is challenging since many of the regional and local networks correspond to independent projects and the available information was generally limited and heterogeneous (López-Ballesteros et al., 2018), with short term data availability and reliability.

Within SEACRIFOG activities, a critical analysis of the main research infrastructures and monitoring networks in Africa, considering their interoperability with the European counterparts and their accessibility for both data providers and users has been carried out. In particular climate system-related observation networks in Africa, and the variables needed for a comprehensive system have been more in detail analysed in D3.1, which documented the existing observation networks potentially useful for the purposes of observing the net climate forcing from Africa; either in their own right since they already collect required variables, or because they could be enhanced with instruments to collect missing variables. The survey considered hundreds of sites covering all observation domains: the land, atmosphere, freshwater, coastal and marine, and included surface-based, airborne and satellite platforms.

3 RESULTS

The most prominent and common issues raised, as inputs from interaction with stakeholders, were concerning data and metadata availability, accessibility, usability, interoperability, resolution and data quality. Capacity development particularly training programmes are needed for GHG monitoring as well as for ArcGIS software. The importance of sharing data and knowledge (i.e. methodological guidance and research results) and the need to develop not only technologies and research infrastructures but also strong and collaborative networking was emphasized. Decision-makers at various levels need an improved access to current know-how and capabilities on new technologies and best practices while taking in proper consideration also local and traditional knowledge. Beside scientific and technical aspects, the solution to part of constraints must be a comprehensive approach considering also socio-economic dynamics which may influence the success and the long-term sustainability of RI network Science alone is not enough, thus mediation among scientists and stakeholders along the entire chain of end users could help in facing some of the crucial aspects. Many efforts are in place but mostly fragmented, with inadequate coordination and connection among institutions. A coherent and thorough analysis and prioritization of all these issues will help in developing a basket of options suitable for specific "on field" conditions, at national or regional level. Here ahead, a brief summary of main results from stakeholders contributes and results from the activities of the different tasks.

3.1 GHG OBSERVATIONS, CARBON STOCKS AND CLIMATE CHANGE MITIGATION

3.1.1 Data, knowledge and capacity needs and gaps

A great common consensus was reached identifying the big challenge in the low data availability and/or accessibility in Africa, concerning all the research areas considered. Data sharing needs to be improved, it is noted that it is often hard to access data and these are not shared readily. Stakeholders agreed that data, where available, are often spread, with no real network connecting them, and there is no sustainability of the observation systems on the long term. There is scarce continuity on data collection which come often from short-term research projects and the limited spatial and temporal coverage on collected data. The need for data repositories with high performance computers jointly with data management skills is evident and often combined with inadequate assortment of technology and local knowledge. Data is needed to improve the close of the carbon budgets and improve the regional balance of carbon fluxes (not only atmospheric, or remote sensing, but also in situ data are needed). There is an increasing need and use of remote sensing data and GIS applications. High relevance has the spatial resolution: high resolution vs low resolution (e.g. farmers need local scale data but most of the info they receive is at higher scales). This lead to the issue of data format. The information is needed in a format that can be understood and used and the interoperability of data from different sources as well as quality of metadata need to be guaranteed. The inaccuracy affects not only the previsions but often also the emission factors which are often not shaped for Africa's contest. If considering data to compile GHG emission inventories, these are very coarse and lacking in accuracy. Data quality also means data up-to-date: some data are not collected frequently enough for reporting, furthermore, since countries are non-

Annex I parties to UNFCCC, most of their GHG emission inventories are calculated based on Tier I (simpler GHG accounting methodology with adoption of default factors)[8] indicators and coefficients with consequent paucity of detail. Data gaps in national, regional and continental GHGs observations in Africa are a common reality. Guidelines for reporting should better address the necessity for capacity-building of officials to understand and implement the guidelines data sharing policies to be strengthened or developed. Knowledge gaps may have severe influence of land management (e.g. Rangeland management) and consequently on soil carbon pools and sequestration potentials. Knowledge gaps are also reported on carbon stocks and GHG emissions particularly in savanna, woodlands and forest ecosystems. Data used for GHGs reporting do not usually originate from the reporting country and are taken from elsewhere. Capacity building is needed for data management, full exploitation of the (human) capacity potential needs to be put into effect proficiently. Accordingly with results of deliverable 4.2, it has been recognized the scarce presence of terrestrial in situ datasets and products, particularly those that are long-term and continuous in nature. The spatial coverage of in situ observations is thin and patchy. There is a need to cover the different biomes and ecosystems more homogeneously, particularly those areas with potentially important GHG source/sink dynamics and rather low human disturbance. As affirmed in del 4.2, "data coverage often jumps at national land borders, which can relate to a step change in the actual density or reporting frequency of observations, or alternatively be due to data accessibility and data policy issues. These issues can result in inconsistency within products that span nations and potentially introduce errors where the step changes are not understood by users. For example, resolution and confidence in a product may be assumed to be consistent across borders, where this may not be actually the case, resulting in poor decisions being made because based upon false assumptions".

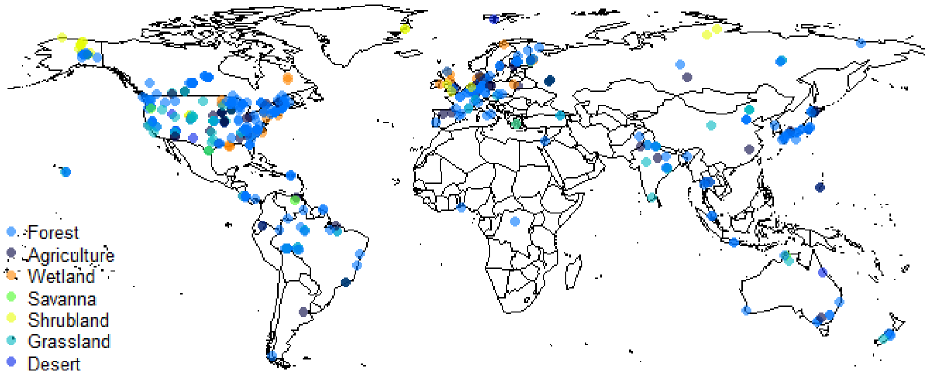
3.1.2 Infrastructures

Existing gap in C and GHG research in African countries

Research on carbon (C) and greenhouse gas (GHG) emissions is very critical to deal with rapidly increasing atmospheric GHG concentrations and the research should be carried out globally- not only developed countries but also African countries since both have different sources and sinks of GHG. However, GHG research has not been widely conducted globally. By 2000, soil carbon dioxide (CO_2) flux measurements were conducted at 1815 sites in 42 countries (Fig. 12). By 2016, soil CO_2 flux measured sites were extended to 6625 sites in 75 countries (Fig. 12). Between 2000 and 2016, the measured sites increased 3.7 times and the measured countries increased 1.8 times. The substantial increase of measurements might be attributed to enhanced interest in the research with fast African highly advanced sensors and data logging technologies. Although the measurement substantially increased in the periods still majority of measurements were carried out in only a few countries. From 2000 to 2016 the measurements in Africa have not significantly increased and are critically underrepresented compared to their importance in global GHG budgets

[8] **Tier 1 :** methods are designed to be the simplest to use. Country-specific activity data are needed, but for Tier 1 there are often globally available sources of activity data estimates (e.g., deforestation rates, agricultural production statistics, global land cover maps, fertilizer use, livestock population data, etc.), although these data are usually spatially coarse. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_01_Ch1_Introduction.pdf

(Fig. 13). In terms of continental scale, the measurements in Africa and South America have not increased and critically under represent compared to their importance in global GHG budgets (Fig. 13).



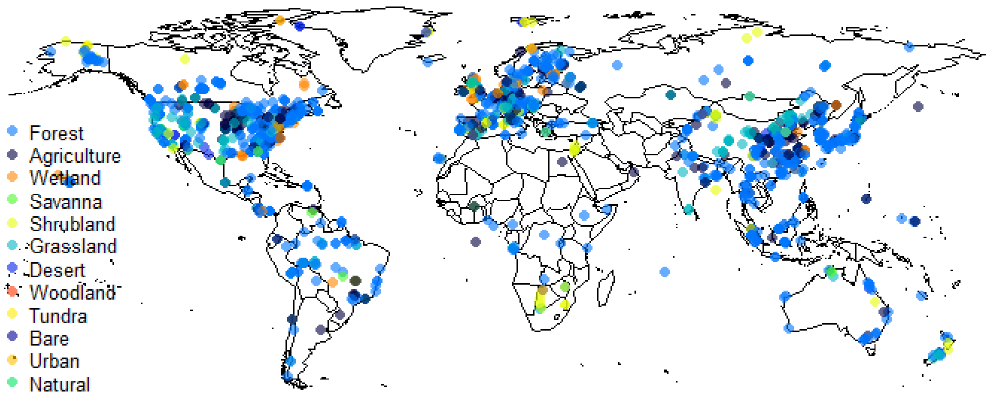


Fig. 12. Global distribution of observed soil carbon dioxide emissions by 2000 (above) and 2016 (below). Data Source: https://github.com/bpbond/srdb Credit: Giacomo Nicolini

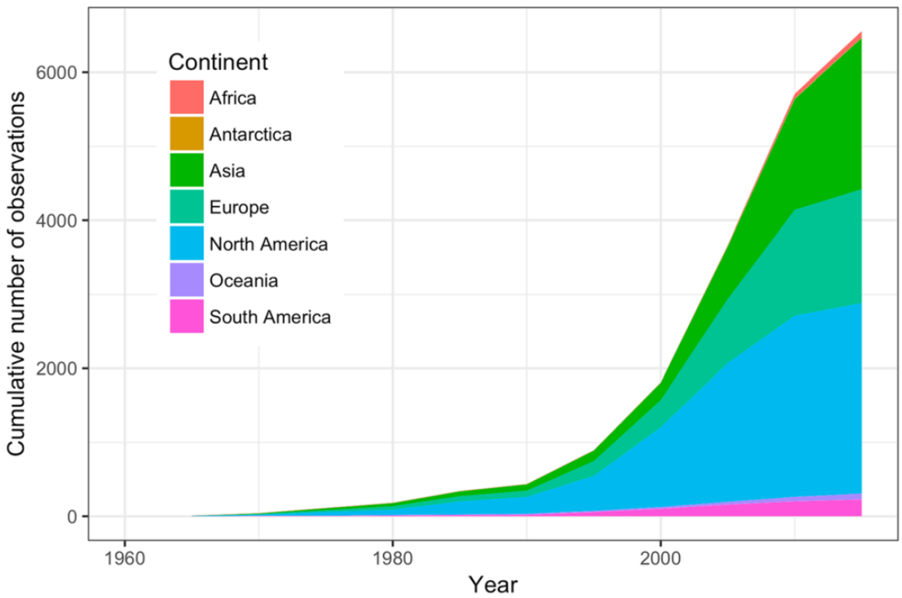


Fig. 13. Number of published soil carbon dioxide emissions observations in each region over time (Bond-Lamberty, 2018). Data are from the SRDB (Bond-Lamberty & Thomson, 2010a), accessed from https://github.com/bpbond/srdb.

Many efforts are in place, but mostly are fragmented, with no coordination, no connection among institutions, with low sharing of information and low accessibility of data. Policy is often published without due consideration of the infrastructure and funding implications, resulting in a weak link between policy and infrastructures. Citizens science could emerge as a new kind of low-cost monitoring infrastructure in Africa. For instance, accordingly with stakeholders feedbacks, GHG observation infrastructure in Zambia, Botswana, Angola, Namibia are hardly available. If there, it is unclear what happens to the data and how the data can be accessed.

As concerns sustainability, the GHG observation infrastructure is based on short lived projects lead by international agencies, which results to be not operational in the long term. As of July 2018, a total of 47 existing and planned environmental infrastructures were identified (Lopez Balestreros et al., 2018) with a combined total of hundreds of observation sites. According to deliverable 3.1, the total will likely continue to grow somewhat as new networks are discovered or come on stream. The survey covered all observation domains: the land, atmosphere, freshwater, coastal and marine, and included surface-based, airborne and satellite platforms. While a good start, the existing networks are deficient for a comprehensive system in several regards: some key variables are missing; the spatial density or distribution may be inadequate; the data are not routinely and reliably available in the public domain; the achieved accuracy may be insufficient; and some observation domains are less developed than others.

Fluxes of trace gases including GHG between ecosystems and the atmosphere have been investigated using eddy covariance (EC) (e.g., Baldocchi, 2014). EC measurement also lacks in African countries (Fig. 14). By 2015, globally 23% of ecoregions are sampled by EC measurements. Among the ecoregions, Africa (9%), Oceania (excluding Australia, 5%) and South America (12%) are particularly poorly sampled (Hill et al., 2017). A total of 11 active EC stations were recording flux data across Africa, with 8 of them located in South Africa in 2018 (López-Ballesteros et al., 2018) while there were more than 459 active EC stations globally in 2016 (https://fluxnet.fluxdata.org/about/history/, Baldocchi, 2014). At the country level, wealthy countries can make EC measurements in a higher proportion of their ecoregions and with more replication (Hill et al., 2017).

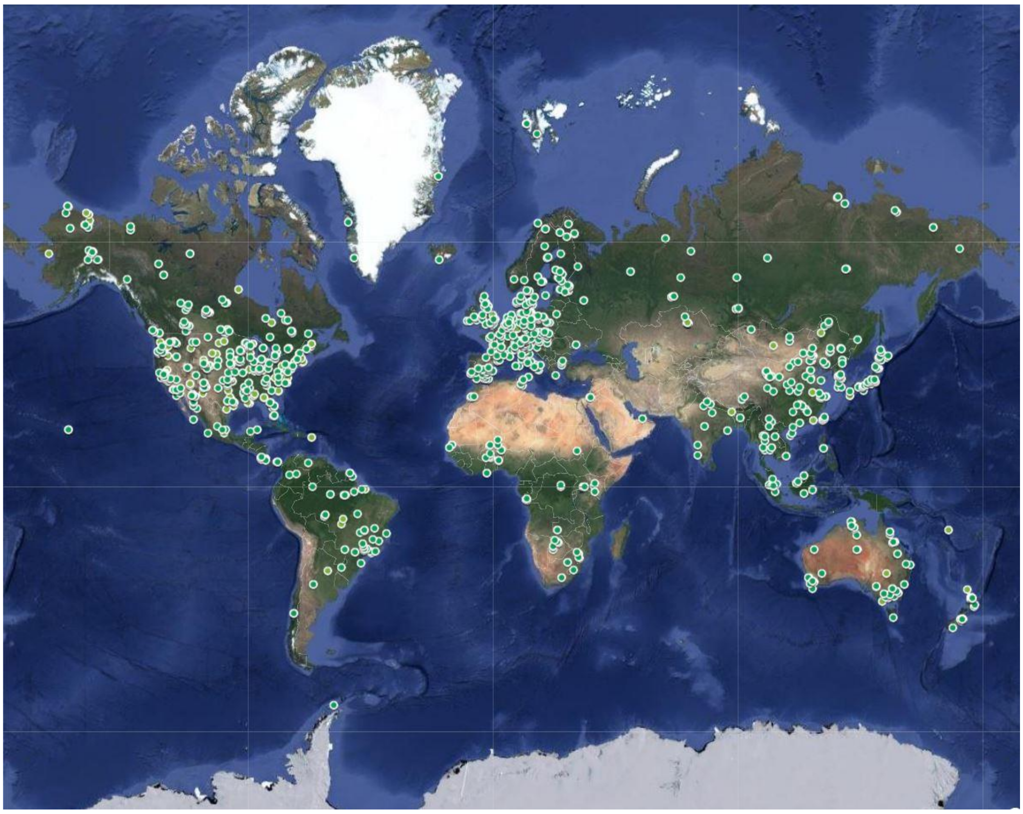


Fig. 14. Map of past and present eddy covariance measurement locations (a total of 2029 measurement locations[9]).

The lack of available data results in serious uncertainties in our understanding on the effects and hinders our progress to develop strategies for mitigating any negative impacts.

Overall, in spite of increasing interest and fast African highly advanced technologies for carbon and GHG research, great lack of data still exist in African countries and the gap hinders further progress of our understanding on carbon and GHG dynamics and African mitigation strategies.

From the stakeholders' feedbacks it emerged that among the possible options, the European approach for an RI network on GHG observations was recognised as not being directly applicable to Africa, for different reasons, of which the most important are: high costs for implementation and maintenance, lack of qualified personnel and specialised companies, problems with energy supply, accessibility and protection of field sites, and challenging eco-climatic conditions.

3.1.3 Obstacles

The obstacles can be summarized into inadequate financial resources above all because short-term economic interests usually prevail over long-term environmental interests. More in detail, there may be various barriers hindering African countries conducting C and GHG research and the barriers would be different by research topic and countries. Among them, according to the analysis made, knowledge and information, technical, financial and policy aspects results to have a remarkable impact.

[9] *Source: Burba G., 2019. Illustrative Maps of Past and Present Eddy Covariance Measurement Locations: I. Early Update. Retrieved Feb 22, 2019, from https://www.researchgate.net. DOI: 10.13140/RG.2.2.25992.67844*

1. Knowledge and information aspects

C and GHG research is a newly emerging scientific field and relevant information has been rapidly increasing and newly updating. Therefore, newly updated knowledge and information can be a back bone of the research from the initial stage of planning to the last stage of publishing results of the research. In the aspect of having updated knowledge and information, developing countries have very weak capacity. Web based knowledge systems have been quickly developing and access to knowledge and information become much easier than previously. For instance, majorities of newly updated knowledge and information including C and GHG research are often available through electronic journal repositories. However, developing countries have difficulty to access them since many of them still lack of internet service and they cannot afford subscription fee for electronic journal repositories charged by the service providers. Overall, limited access to updated knowledge and information on C and GHG research is a critical barrier hindering African countries conducting C and GHG research.

2. Technical aspects

C and GHG research often requires highly advanced technical supports such as advanced instrument, computer software or skilled man power that has relevant knowledge and experience. The instrument or software required for the research may not be available in developing countries and it may take long periods to bring them from oversea due to logistical issues and custom process. Also it is hard to find out knowledge and experience, equipped skilled man power to operate advanced instrument and software, and it takes substantial amount of time and investment to produce the skilled man power. The absence or the time delay can discourage initiation of the research or fail to manage the research schedule properly. Even if the instrument, software and skilled man power could be obtained through supports from external collaboration there are still critical issues remained. External collaboration often exists during only certain period in which externally funded collaboration project lasts. The more research rely on supports from external collaboration the more question can be raised on sustainability of research.

3. Financial aspects

C and GHG research often requires very large amount of financial support. The costs for hiring skilled man power, purchasing required instrument and software, and their operation and maintenance are often very high and sometimes it could be beyond the financial capacity of any institute that African countries can have. In addition, due to complicated experimental design and required data collection in large spatial or long-term temporal scales, conducting research can be also very expensive and requires long-term investment with high risk on failure of achieving expected outcomes. In the other hand, there is a serious lack of research grant in developing countries and it makes difficult to initiate C and GHG research or sustain the research on the long run.

4. Policy aspect

African countries often struggle to manage with their local ecological and environmental issues and they are intended to focus on them rather than global issues such as C and GHG issues. Therefore, the importance of C and GHG research may not be well recognized by developing countries.

Consequently, policy makers or research and science managers in developing countries are not willing to put C and GHG research into priority in the research and education programs or relevant policy making process and allocate research budget and resources for the research.

3.2 LAND USE CHANGE IMPLICATIONS ON FOOD SECURITY

Land use is defined as the process of "total arrangements, activities and inputs that people undertake in a certain land cover type" to produce, change or maintain it, while *land cover* refers to "the observed physical and biological cover over the earth's land as vegetation or man-made features" (FAO, 1997; FAO/UNEP, 1999). Land use and land cover change is a term used for the human modification of the earth terrestrial surface. Much of the world's natural land cover has been modified by human activities, resulting in ecosystem degradation and biodiversity loss worldwide (Hamza & Iyela, 2012). The driving forces behind land use pattern include all factors that influences human activity, including local culture (food preferences), economics (demand for specific products, financial incentive), environmental condition (soil quality, terrain and moisture). Land use change is largely driven by the decision of the people and population growth, declining household farm size and income (Ogechi and Hunja, 2014). Land resources are used for a variety of purposes which include agriculture land use, reforestation, settlement, near-surface water and ecotourism but the main purpose for land use change, above all in Africa, is to obtain food.

Food production is the cultivation of food crops with special regard to maximization of the total yield gained per acre in one planting season. The problems of food supply and farming are among the most confusing, diffuse and frustrating of mankind contemporary dilemmas. Food security refers to the availability of food and one's access to it while food problem is the apparent inability of the world's people to feed them adequately and consistently (Hamza & Iyela, 2012). But land use change and particularly expanding agricultural lands to enhance food security can be a tricky issue under a changing climate, since it can result in loss of carbon stocks and increasing GHG emissions, particularly in SSA. In some cases, even an estimated gain in terms of projected enhanced yield is not necessarily enough to transform an agricultural system because farmers decide land use in a context of culture, economic forces, and sophisticated relationships within their societies. The ability of livelihood systems to adapt or mitigate climate change effects may depend on the character of the drivers most influential for the locality and the adaptive capacity of the human system in question. Thoughtful land use and land management could thus play a major role in coping with climate change and adapting human livelihood systems, such as decentralized ranching and shifts in crop production areas. Climate impacts of land use and land management should be considered as a primary driver of food production risk (Moore et al. 2012).

3.2.1 Data needs and gaps

Data availability and/or accessibility is a focal issue for land use change implications on food security. Land-use change has been known to affect CO_2, CH_4 and N_2O emissions and land-use change occurs in African countries due to agricultural expansion following deforestation. Various global meta-analyses reporting the effect of land-use changes on soil organic carbon (e.g., Shi et al., 2016; Kim and Kirschbaum, 2015; Don et al., 2011) and CH_4 and N_2O emission (e.g., McDaniel et al., 2019; van Lent et al., 2015; Kim and Kirschbaum, 2015) commonly found that very low amount of data was available from African countries compared to Europe and North America. According to a global meta-analysis reporting the effect of land-use change on CH_4 and N_2O emission (McDaniel et al., 2019), among 62 studies, studies carried out in Africa and Asia were only 5% and 11%, respectively while studies carried out in Europe and North America were 21% and 33%, respectively. The results suggest that there exists a significant gap in GHG emission research in African countries (Kim et al., 2013 and 2016). Information is needed in a format that can be understood and used. Stakeholders refer about problems of data visibility when talking about hidden information related to illegal activities (illegal logging for charcoal production for example). Maps are a fundamental tool for development and for establishment of land use policy. Satellite images are very useful for information sharing and communication with stakeholders at different levels both as people on field and as researcher or policy makers. The use of remote sensing data and GIS applications is really needed as well as information regarding the synchronization between farmer's needs, weather conditions and governmental helps (seeds and fertilizer). Inputs from Zambian stakeholders suggest that needs are focused on access to data in general and specifically on soil data, meteorological data production and availability (Zambia: accurate weather forecast missing, only 33 meteorological station in the country). The centralized structure needs to be decentralized in order to reach a wide range of users. Transboundary information share is needed and, as underlined by Botswanans, link between research and extension officers is weak and need to be strengthened.

3.2.2 Knowledge needs and gasps

Inadequate combination of technology and local knowledge are coupled with inadequate equipment in terms of computer software (GIS, remote sensing). Furthermore, there is no information about water resources, the use of water resources is inadequate for absence of communication with local farmers (e.g. ground water mostly not used in Ghana). In Zambia diversification of crops is governmental issue, but it is not applied by farmers, the Agricultural National Plan exists, but people do not know about it also because of limited capacity of extension officers, lack of training and land reform which led to farming without a proper agricultural knowledge.

3.2.3 Capacities

As underlined above, there is not full exploitation of the (human) capacity potential and it is evident the need of more cooperation among the farmers category (e.g. cooperatives for accessing to rural bank loans).

3.2.4 Infrastructures

Investments are needed, e.g. into technologies and equipment and in this contest, the role of government subsidies is crucial. There is a need for information platforms/centers like SASSCAL and WASCAL. There are not processing infrastructures and where farmers often are not aware of them. In Angola as in many other African countries, food waste is due also to lack of transport infrastructure. Transport infrastructures are not efficient and sufficient to ensure the connection from farming areas to the markets. In Angola, the monitoring of land use change (LUC) using earth observation is performed by the National Remote Sensing Centre but there is a lack of observational system for natural hazards, although efforts are in place for risk mapping preparation.

3.2.5 Obstacles

Inadequate resources

Inadequate resources influence at various level the impact of land use and land use change on food security. Resources are meant not only related to land affordability but also in terms of prices and more specifically:
- price insecurity of agricultural products
- need to reform the price system, no more price per bags of product but price per kg of product
- not adequate and fair price for products

Land use changes and land related issues

Land use changes and consequent impacts on food security are result of different drivers which have been identified by stakeholders as follow:
- Land tenure inequality. Lack of secure land tenure among rural people. Land tenure depends where people are from, even in the same country the land tenure system may vary. Differences appear when land is private land, traditional administrated or public administrated land and so the rights on the land and its products.
-Land suitability in terms of land suitable for agriculture (that has been reduced by the effects of climate change and by the human pressure)
-Land fragmentation
-Land conversion from farming to urban areas. Urbanization is rather rapid and vastly horizontal (low-floor buildings)

Illegal activities

-Pressure on farming lands for illegal mining, land sold for real estate development
- Illegal logging (mainly for charcoal production)

Legal and illegal activities

- Land grabbing
- Energy demand- e.g. charcoal production leading to deforestation (Angola: Slash and burn practices for agricultural land, in Namibia bush clearing for biomass for biofuel and charcoal. Charcoal and timber logging drivers for LUC).
- Mining (Botswana: Mining for diamonds in the game reserves (Kalahari Reserve) is a problem).

Agricultural related practice and issues

- Inadequate information and integration of indigenous knowledge on mitigation of insects/pests infestation
- Beef production impact (e.g. in Namibia: Bush clearing for feed stock)
- Water management (e.g. Zambia: Agriculture is intensified, often monocultures established which are heavily dependent on rains with very little investment in rain harvesting and storage)
- Lack of interest for agricultural sector by youth lead to a gradual shifting of labor force from the fields to the urban areas.
- Low infrastructure development (roads and direct connections) able to guarantee the access to the market as well as total lack of storage and processing facilities.

- Governmental policy's (especially in case when subsidies for seeds, fertilizer, etc. increase the expansion of agricultural land)

Side effect of economic development

- Urban/residential development- urban migration as result of population growth
- Tourism pressure
- Economic pressure for converting to other land uses

3.3 CLIMATE SMART AGRICULTURE

"Climate-smart agriculture (CSA) as defined and presented by FAO at the Hague Conference on Agriculture, Food Security and Climate Change in 2010, contributes to the achievement of sustainable development goals and is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible. CSA is an approach for developing agricultural strategies to secure sustainable food security under climate change. CSA provides the means to help stakeholders from local to national and international levels identify agricultural strategies suitable to their local conditions (FAO, 2019). Widespread changes in rainfall and temperature patterns threaten agricultural production and increase the vulnerability of people dependent on agriculture for their livelihoods, which includes most of the world's poor. Climate change disrupts food markets, posing population-wide risks to food supply. Threats can be reduced by increasing the adaptive capacity of farmers as well as increasing resilience and resource use efficiency in agricultural production systems. CSA promotes coordinated actions by farmers, researchers, private sector, civil society and policymakers towards climate-resilient pathways through four main action areas: (1) building evidence; (2) increasing local institutional effectiveness; (3) fostering coherence between climate and agricultural policies; and (4) linking climate and agricultural financing. CSA differs from 'business-as-usual' approaches by emphasizing the capacity to implement flexible, context-specific solutions, supported by innovative policy and financing actions (Lipper et al. 2014). CSA integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges. The magnitude, immediacy and broad scope of the effects of climate change on agricultural systems create a compelling need to ensure comprehensive integration of these effects into national agricultural planning, investments and programs. The CSA approach is designed to identify and operationalize sustainable agricultural development within the explicit parameters of climate change (FAO, 2013). CSA can offer substantial benefits to farmers in Africa in terms of increased productivity and incomes, better risk management and improved resilience to climate change and for this reason it has become a key development goal. Despite this focus, the adoption of CSA practices and approaches by smallholder farmers has been slow, fragmented and largely un-sustained. The adoption of CSA depends on accessibility, promotion and training about specific technologies and increased access to the market. However, there are many key behavior change factors including wider social, political, and institutional environment in which agriculture is embedded. These include broader livelihoods identity roles and responsibilities (including gender) decision-making timeframe and farmers risk management perspectives. These factors all greatly shape the incentives to adopt CSA approaches (USAID, 2016). So CSA cannot be considered a prescribed practice or a specific technology that can be universally applied. It is an approach that requires site-specific assessments of the social, economic and environmental conditions to identify appropriate agricultural production technologies and practices. A key component of CSA is integrated landscape approach that follows the principles of ecosystem management and sustainable land and water use. At the farm level, CSA aims to strengthen livelihoods and food security, especially of smallholders, by improving the management and use of natural resources and adopting appropriate approaches and technologies for the production, processing and marketing of agricultural commodities. At the national level, CSA seeks to support countries in putting in place the necessary policy, technical and financial mechanisms to mainstream climate change adaptation and mitigation into agricultural sectors and provide a basis for operationalizing sustainable agricultural development under changing conditions (Williams et al. 2015). CSA faces a number of challenges related to the conceptual understanding, practice, policy environment and financing of the approach. Specific challenges in need for intervention are related to needs and gaps as outlined in the paragraphs below.

3.3.1 Data and knowledge needs and gaps

The most prominent issue in terms of data and knowledge, aside the low data availability and/or accessibility and usability, results to be, among the others, the incorrect and scarce use and consideration of local and traditional knowledge. There is evidence also of inadequate awareness about climate change impacts in the agricultural sector and applicable climate smart agriculture practices. Data for farmers are often non available at local scale and the big issue is the need for short term data: from almost real time (early warning) to seasonal forecast and few years, for food security and adaptation. The need for historical data or long-term future predictions is lower. The lack of data and information and appropriate analytical tools can be both at local and national levels. In many African countries, there are no long-term climatic and landscape level data**.** Where some data exist, they are dispersed and difficult to access. Global models of climate change are at scale and resolution difficult for local, national or regional managers to work with. Capacity and analytical tools to downscale the results of global models to regional, national and watershed scales are not readily available in most countries. As a result, decision makers lack knowledge of current and future projected effects of climate change in their country and their implications for agricultural practices, food security and natural resource management. The lack of information, limited human and institutional capacity as well as lack of research-based evidence impedes the ability of decision makers to target CSA implementation to areas most at risk and to implement adequate financing plans. Initiatives such as the EPIC programme[10] in Malawi and Zambia which focuses on building the evidence base to identify country specific climate smart agricultural practices; increasing policy and research capacity to integrate climate change issues into agricultural and food security planning

[10] **Economics and Policy Innovations for Climate-Smart Agriculture (EPIC)** programme - http://www.fao.org/climatechange/epic/home/en/

and vice versa; and developing investment proposals for scaling up CSA activities that are linked to climate financing sources as well as traditional agricultural investment finance sources, need to be scaled up (Williams et al.2015).

Relevance has also the enterprise selection, for best choice of types and quantity of crops. Although farmers have always adapted to and coped with climate variability manifested, for example, in delayed onset of rains, seasonal water deficit and increasing seasonal maximum temperature, they often lack knowledge about potential feasible options for adapting their production systems to increasing frequency and severity of extreme weather events (droughts and floods) and other climate changes. At another level, lack of accurate and timely information and technical advisory services, unavailability and lack of access to inputs, including suitable crop varieties constrain their ability to assess the risks and benefits of CSA and make informed investment decisions. Competing resource use (e.g. labor, cash, biomass) at the farm scale have been a major constraining factor. Furthermore, smallholders in particular face obstacles in gaining access to domestic, regional and international markets (Williams et al.2015).

3.4 UNCERTAINTIES OF SCIENTIFIC MODELS ON CROP YIELD

3.4.1 Knowledge needs and gaps

Uncertainty analysis from literature review

According to Refsgaard et al. (2013) from the management point of view, uncertainty is, quite simply, the lack of exact knowledge, regardless of what is the cause of this deficiency. Murthy (2004) outlined various crop growth modeling approaches such as Statistical, Mechanistic, Deterministic, Stochastic, Dynamic, Static and Simulation, descriptive and explanatory. In the case of this study, the type of models which express the crop yield as response or relationship between yield or yield component (module) and weather parameters are of concern. We will not focus our attention in the biogeochemical sub-models (W = water; N = nitrogen; C = soil organic carbon; P = phosphorous; K = potassium; CH_4= methane). It has been asserted that crop model uncertainty limits assessments of future food production (Challinor et al. 2014b). For this purpose, a summary of crop yield models applied in the African agro ecological zones was underlined, with the focus on yield component of these models, their spatial resolution or scale and related uncertainties (Tab.2).

Table 2: Uncertainty analyses of crop yield models applied in various African Agro-Ecological Zones

MODELS	AUTHORS	SOURCES OF UNCERTAINTY	UNCERTAINTY ANALYSIS	OBSERVATIONS / COMMENTS	SPATIAL COVERAGE	CROPS TYPES
DSSAT	Boogaard et al. (2014)		R^2 = 0.38	Model yield is linear correlated to observed yield with very low R square. Uncertainty in yield forecasting is high.	Southern Africa	Maize and Wheat
	Zinyengere et al. (2015)	▪ Data is often riddled with gaps and inaccuracies, needing further processing ▪ Climate stations are sparse	▪ Relative difference ranged from -12.2 % to +2.36 % ▪ R^2 range from 0.70 to 1 depending the crop type	DSSAT estimated well the observed mean crop yields, estimating mean yields within -12.2 % and +2.78 % of observed yields across all locations	Lesotho, Swaziland, Malawi	Maize, sorghum and groundnut
EPIC	Wang et al. (2005)	▪ input-data, and the choice of model ▪ uncertainties due to model parameters (Biomass-energy ratio, Harvest index, Potential heat units, Water stress-harvest index) or calibration	▪ The optimal parameter set identified through the automatic parameter optimization procedure gave an R^2 of 0.96 for average corn yield predictions	The uncertainty subjects to decrease if applying model calibration or input data quality control EPIC was dependable, from a statistical point of view, in predicting average yield	Global	Maize
	Skalsky (2017)	▪ input-data, and the choice of model ▪ uncertainties due to model parameters ▪	▪ the global yield change less than 30% by the 2080s	▪ The uncertainty subjects to decrease if applying model calibration or input data quality control. ▪ Calibration has a larger effect at local scales, implying the possible types and locations for adaptation	Global	Maize

Local and Global Spatial Regression (CAR and GWR models)	Imran, Zurita-Milla, and Stein (2013)	▪ Crop yield was related to rainfall and topography in semiarid and subhumid agro-ecological zones ▪ Soil properties and labour availability mainly affected millet and sorghum yield in the semiarid zone	▪ For CAR model adjusted R^2 range from 0.50 to 0.76 for the semiarid zone, and from 0.30 to 0.54 for the subhumid zone ▪ For GWR model, R^2_a values were 0.70 to 0.85 for the semiarid zone and from 0.65 to 0.76 for the subhumid zone	GWR can be used to model spatial variability of crop yields across large areas in West Africa	West Africa (Burkina-Faso)	Sorghum, Millet, Cotton
MAXENT	Estes et al. (2013)		$R^2 = 0$	▪ Suitability is not linear correlated to measured yield.		

Crop yield models and uncertainty analysis-based experts viewpoints

The most identified crops yield models (Tab.6) and which target various agro-ecological zones in Africa based on expert viewpoints are:

1. Sara-H and GEPIC for large scale analysis,
2. WOFOST
3. DSSAT and APSIM have robust physiologically based crop growth models and can simulate a range of important African crops

According to the data availability, in the most cases of our investigations (about 80% of the sample) data availability is not a problem. The data accessibility remains a challenge to overcome due to the low confident level of scientists or authors. Accessibility of in situ-based data still not open to the audience or readers. For example according to one of our respondents, “The data for model calibration and evaluation are usually available but may not be accessible to the model user. For instance, there is a lot of useful data out there with the NARS (National Agricultural Research Systems) and CGIAR (Consultative Group on International Agricultural Research) centers but a model users may not be able to have access to this type of data because of data protection laws etc.”.

In fact, some journal required data from authors when publishing and this must be the novel approach that must be the way to forward to facilitate research analysis and filling the knowledge gaps and data needs.

Table 6. Description of models used by experts

MODEL	COVERAGE AREA	MODEL TYPE	DATA FORMAT	IMPLICATION FOR FOOD SECURITY	MODEL LIMITATIONS	SOURCES OF UNCERTAINTY IN MODEL OUTPUT
PEGASUS	Global	Mechanistic	Netcdf	The model can support analysis on future global crop production	accuracy of global datasets, especially in the context of Africa	✓ simulation of processes related to crop water use (evapotranspiration), ✓ soil water balance, soil data, ✓ representation of small-scale multi-cropping systems, climate data
WOFOST	Country level	Mechanistic and Dynamic	N/A	The model synthesize the effect of weather/climate dynamics on crop development and growth considering local agronomy, soils, topography	Currently does not include dynamics of nutrients in the soil	Mainly input related: ✓ accurate rainfall data, ✓ accurate crop calendars, ✓ accurate description of local variety (yield potential, growth duration), ✓ accurate yield statistics, soil fertility (in case of modelling nutrient stress)
DSSAT	Field	Dynamic		Dynamic simulation models that integrate the impact of variable weather with a range of soil, water and crop management choices can be used to assess various technological options to improve food production e.g. identification of suitable crop varieties, fertilizer and crop management options	Currently DSSAT does not simulate effects of pest and diseases, potassium fertilization and intercropping. The soil water balance component is based on a simplified tipping bucket model and does not simulate various hydrological processes.	A major source of uncertainty in model output are the soil input parameters rather than the crop genetics especially in low input agricultural systems as in Africa.

3.4.2 Data needs and gaps

Available data and metadata on crop yield models-based literature review

The table 7 provides link to the available data on crop yield based on the literature review. In the most case the database was mostly about the weather data which was link to satellite and rain gauge information.

Table 7: Available data and metadata on crop yield models-based literature review

MODELS	AUTHORS	SPATIAL COVERAGE	DATA SOURCES
CGMS-WOFOST	Boogaard et al. 2014	Europe and Africa	https://www.eumetsat.int/website/home/News/DAT_3268121.html
DSSAT	Zinyengere et al. 2015	Southern Africa	Meteorological stations located in each study district
Local and Global Spatial Regression (CAR and GWR models)	Imran et al. 2013	West Africa (Burkina-Faso)	- AGRISTAT http://www.insd.bf/n/nada/index.php/catalog/20/accesspolicy, - https://www.eumetsat.int/website/home/Data/Products/Formats/index.html
EPIC	Wei Xiong et al. 2016	Global	http://cmip-pcmdi.llnl.gov/cmip5

Data needs and gaps on crop yield model-based literature review

Information gathered from literature review revealed that, in climate modelling, improvements in parameterization and increases in model complexity and spatial resolution have resulted in enhanced model performance (Delworth et al. 2012). For this purpose, there is an urgent need to develop standards for weather station equipment and sensors installation and maintenance. It is also important that a uniform file format is defined for storage and distribution of weather data, so that they can easily be exchanged among agro-meteorologists, crop modelers and others working in climate and weather aspects across the globe. Easy access to weather data, preferably through the internet and the World Wide Web, will be critical for the application of crop models for yield forecasting and tactical decision making. Previously one of the limitations of the current crop simulation models was that they can only simulate crop yield for a particular site.

Expert's viewpoints on data needs and knowledge gaps

➢ Data needs for Africa

In the field of crop yield models under the climate change conditions, according to the respondents the data needs for Africa are as follow:

- Growing seasons,
- Crop irrigated and rainfed harvested areas,
- Available soil water capacity
- Accurate rainfall data,
- Accurate agronomy data
- Lack of long term observations of the impact of climate variability on crop yields and various other processes
- Lack of long-term quality weather data due to the low density of climate stations

➢ Knowledge gaps for Africa

- Simulation of multiple cropping systems and tropical crops
- Nutrient stress modelling (soil fertility),
- Mixed cropping

3.5 UNCERTAINTIES IN OBSERVED PRECIPITATION PRODUCTS AND WEATHER FORECASTING

3.5.1 Knowledge needs and gaps

Observational precipitation products

Generally, Africa has a great challenge in term of observational datasets due to the limited or lack of surface-based observation platforms. Estimating rainfall amount, different instruments are used including ground observations from rain gauge and estimates inferred from satellite observations (Tab.8). Each of these is associated with specific rainfall estimation uncertainties. The most utilized type in Africa is the rain-gauge and its records have been available for hundreds of years. As technology has advanced, rain gauge has become more accurate in determining the amount of rainfall at a particular location. However, Rain gauges present some weaknesses such as being able to observe precipitation at only one site in space, often underestimating rainfall amounts, deficiencies over most oceanic and sparsely populated areas (Kidd, 2011, Xie, 1997). Given the limitations of rain gauge datasets within many regions around the world, the use of satellite rainfall products appears to be a feasible solution to fill the gap. The satellite estimates may complement sparse rain gauge data by providing more spatially a wide and consistent coverage of the globe (Kidd, 2011, Joyce et al., 2004, Sorooshian et al., 2000). They provide a unique platform to continuously monitor the land, ocean, and atmosphere at various timescales, depending on the type of satellite and the instruments on board. The satellite rainfall estimates over land present some random error and bias probably due to the indirect nature of the relationship between observations and the precipitation, the inadequate sampling, and algorithm imperfections (Xie 1997, Ali et al., 2005a,b). This proves that the full utilization of satellite-based rainfall datasets remains hindered by the uncertainty and unreliability associated with the rainfall estimates.

Table 8: Some characteristics of Rain gauge and satellite estimates precipitation datasets

CATEGORY	SPATIAL AND TEMPORAL RESOLUTIONS	ADVANTAGE	DISADVANTAGE	ERROR	OUTPUT	UNCERTAINTY ANALYSES
RAIN GAUGES	0.5^ox 0.5^o degree grid interpolation Hourly, Daily, Monthly and Yearly	Point measurement, Long records	Low spatial coverage; Biases and in homogeneities; Observer errors;	Random error, mechanical issues, location	Underestimates heavy rainfall events	A lot discrepancies exit in ground-based observations where the errors may arise from differences in the density of observation stations, interpolation method, or simple recording;
SATELLITES ESTIMATES	0.1^o x 0.1^o; 0.25^o x 0.25^o ; Half-Hourly, Hourly, Daily	broad spatial coverage; long-term continuity; automatic data acquisition;	Short records; Biases and in homogeneities, discontinuities; Instrument calibration, changing algorithms	Frozen precipitation, multilayer clouds	Generally Overestimates rainfall	The different methods used in satellite estimates such as the conversion algorithms of the retrieved electromagnetic signal to a physical parameter like precipitation or by atmospheric factors affect the signal retrieved by the satellite;

Evaluating the uncertainty in gridded rainfall datasets over West Africa

The gridded data referred as observational data are often used to assess the effects of climate change and variability. These datasets have been subjected to comprehensive quality control over the years and take as reference for comparison, with inherent uncertainties in the resultant data products (Bosilovich et al., 2008). The comparison of different precipitation products was performed with different dispersion amongst datasets or in evaluating agreement relationships. Each of these different statistics offers particular information about the error being evaluated in order to quantify the systematic differences between the products (Tab. 9). All these studies indicate inherent uncertainties in precipitation products and making difficult to assess the model performance. This kind of analysis is very essential to highlight the differences in spatial and temporal rainfall estimates and also provide guidance to the choice of gridded rainfall data for assessing the model performance and understanding climate change over the region.

Table 9: Evaluating the uncertainty in gridded rainfall datasets over West Africa

AUTHORS	DESCRIPTIONS	PRECIPITATION PRODUCTS	PERIODS	UNCERTAINTY ASSESSMENT
Mahe et al., (2008)	Evaluate three monthly gridded rainfall data sets and to analyses the consequences of each choosing one of them on the simulated river flows in 5 basins across Burkina-Faso;	CRU, SIEREM and ANAM-BF	1922 – 1998	The three different rainfall grids produce differences in mean rainfall of 4 to 11%, depending on the grids that are compared.
Lamptey (2008)	Conduct a simple analysis of the random and systematic differences between the gauge and satellite monthly rainfall data;	GPCP and GPCC	1979 - 2000	A significant difference between the two datasets is the difference in rainfall amount. These differences are due to the interpolation technique used for the surface data. In addition, the GPCP overestimates annual and seasonal rainfall over the highlands of Cameroon but underestimates rainfall over the highlands of Guinea; while the GPCC fails to capture the bimodal rainfall pattern

				along the Guinea coast;
Liebmann et al. (2012)	Studied the spatial variations in the annual cycle comparing GPCP with TRMM and gauge based Famine Early Warning System data sets	GPCP, TRMM 3B42 and FEWS NET;	1997-2008	Areas with large differences the gauge data often lie somewhere in between GPCP and TRMM, with GPCP biased high;
Sylla et al. (2013)	Presented an intercomparing of different observed gridded daily precipitation datasets in order to assess uncertainties in observation products;	GPCP, TRMM and FEWS	1989 - 2007	Substantial discrepancies are found among the different observational datasets. These may due to a very wide spread among the observed data at a particular space-time coordinate;
Nikulin et al. et al. (2012)	Evaluate different observational datasets over Africa to get an estimate of their accuracy and to encompass their uncertainty;	CRU, GPCP, TRMM-3B42, CMORPH, UDEL and GPCC	1989 - 2008	Large differences are noted among the observed products, which may due to different processing algorithms and different levels of station availability in given time periods;
Kalognomou et al. (2013)	Provide an overview of observational uncertainty various observed precipitation products;	UDEL, CRU, GPCP, TRMM, ERA-Interim and GPCC	1990 - 2006	A poor correlation is noted between the datasets which may attributed to spatial differences within the chosen subregion across the gridded datasets;
Kim et al. (2014)	Examines the uncertainties in model evaluation related with reference data;	CRU, MODIS and TRMM	1998 - 2007	Significant differences are found between the observed data probably resulting from the difference in the observational platform and methodologies;
Gbobaniyi et al. (2013)	Examine the ability of an ensemble of 10 Regional Climate Models and observed datasets in reproducing key features of present-day precipitation and	CRU, GPCP and UDEL	1990 - 2008	Inherent uncertainties are established among the observed products, especially in data sparse areas;

	temperature over West Africa;			
Dutra et al. (2013)	Used of different observational and reanalysis datasets to evaluate concerning their value as monitoring tools for droughts in four African basins;	ERA-Interim, GPCP and CAMS-OPI	1981 - 2010	Significant differences in the quality of the precipitation between the data sets for different river basins in Africa;
Manzanas et al. (2014)	Presented assessment of the suitability of various gridded observational and reanalysis products for studies of precipitation variability and trends over Ghana was carried out;	CRU TS 3.20, GPCC v6, PREC/L, GPCP v2.2, CMAP, GPCP v2.2 TARCAT v2.0, TAMSAT, CAMS-OPI, ARC2, GMet	1961 - 2010	Difference are noted between observed and the inconsistencies are highlighted when analyzing trends of extreme precipitation indicators;
Naumann et al. (2014)	Present a comparison study to identify the main sources of uncertainty in the computation of the drought indicators on their capability to improve drought monitoring in Africa using observed products.	TRMM 3B-43 v.6, ERA-Interim, GPCC v.5, GPCP v.2.2 and CMAP	1998 - 2010	Main differences are noted due uncertainty in the precipitation data sets rather than the estimation of the distribution parameters of the drought indicators;
Matthew et al. (2017)	Assessed uncertainty in estimating long-term mean precipitation using three network observation datasets over West Africa;	CRU, GPCC and UDEL	1971 - 2010	The three observational products showed inherent uncertainties in the spatial variability.

Forecast uncertainty reflects the state of the science

Weather forecasting has been an area of considerable interest among researchers since long. However, it is possible to predict weather using your skills of observation, knowledge of weather patterns and modelling to predict the weather. The weather models are used to predict weather conditions up to 10 days in forecast or with day-to-day basis. One of the most familiar weather forecasting models used is the Numerical Weather Prediction (NWP). This model has extensively analyses, either as large-scale forcings for mesoscale atmospheric simulations in case study experiments or as a full three-dimensional description of the atmospheric and surface parameters for climate research.

Sources of uncertainty in weather forecasting

In order to effectively assert forecast uncertainty, it is important to understand why there is uncertainty in forecasts and where it comes from (Fig. 11).

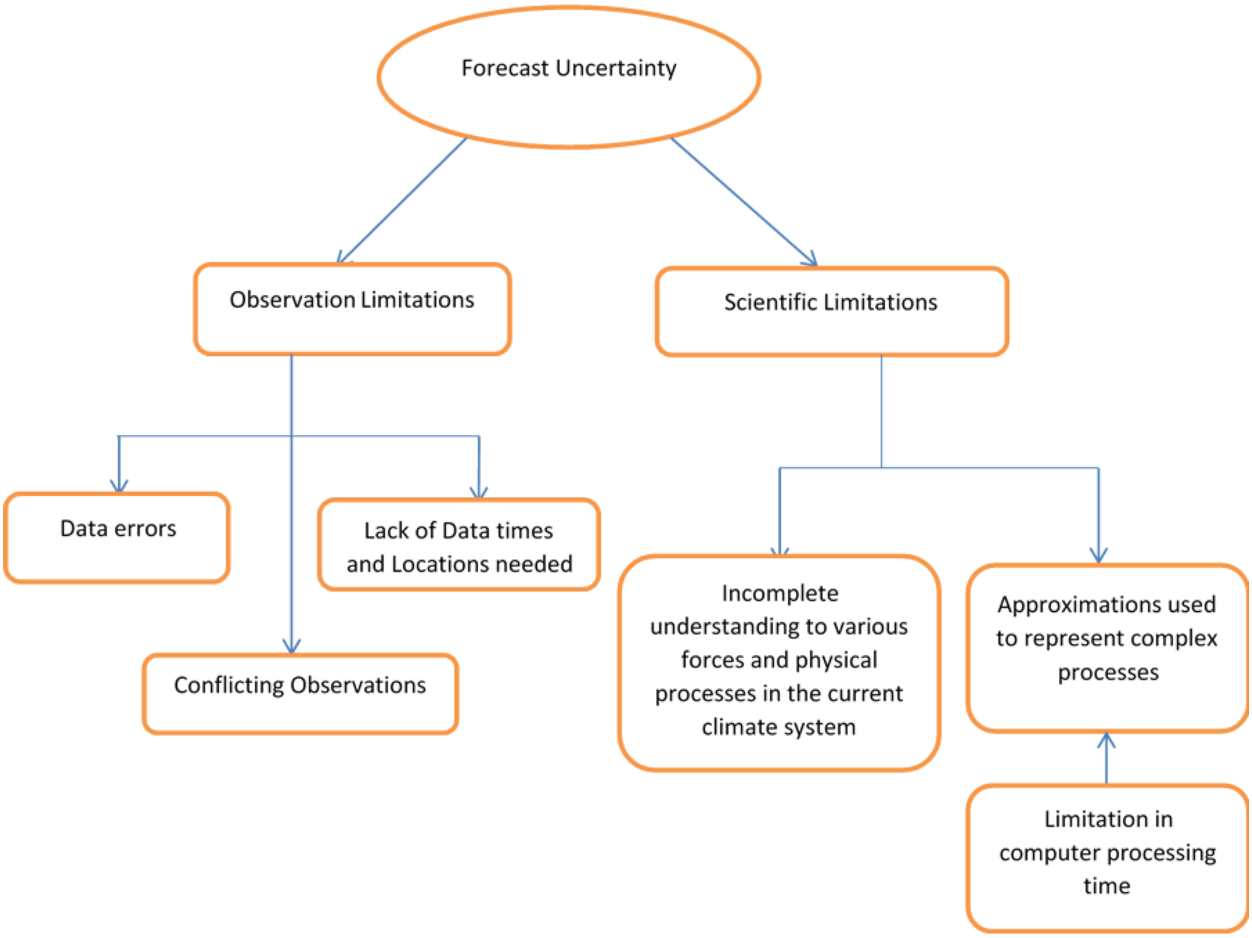


Figure 11: Schematic view of forecast uncertainty (Source, COMET Program)

Background studies of weather forecasting model based on AMMA results

Weather forecasting in Africa has huge potential to benefits of the African nations with large populations dependent on rain-fed agriculture. The seasonal rain is dictated by West African monsoon (WAM) which brings rain over the continent, and therefore essential to the livelihoods of millions. Predicting the WAM remains a major challenge for weather and climate models. This is due to the poor skill of general circulation models GCMs, (Hourdin et al. 2010, Sylla et al. 2010, Xue et al. 2010) and NWP (Fink et al. 2011) models in capturing the characteristics of the WAM and its associated precipitation pattern and variability. Projects such as the international African Monsoon Multidisciplinary Analysis (AMMA) programme (Redelsperger et al. 2006) have already proved the value of focused research on African Weather combined with intensive observations. This project has greatly advanced the understanding of the WAM based on both modelling and observational studies (Redelsperger et al. 2006) but the models showed a poor ability to predict WAM rainfall system over tropical northern Africa (Tab.10).

Table 9: Background studies of weather forecasting model based on AMMA results

AUTHORS	DESCRIPTIONS	NWP MODELS	PERIODS	UNCERTAINTY ANALYSIS
Bock et al., (2008)	Presented NWP model evaluation using both near-real time GPS PWV estimates (as delivered during the AMMA field experiment in 2006) and precise post processed GPS solutions;	ARPEGE, ARPEGE-Tropiques and ALADIN	June to September 2006	Significant deficiencies in NWP model forecasts are evidenced using the precise/reprocessed data set. It also emphasizes the difficulty the NWP models have to handle the atmospheric humidity and atmospheric processes at subdiurnal timescales;
Meynadier et al., (2010b)	Create a special archive of AMMA radiosondes and to re-run the ECMWF data assimilation and forecasting system for the period of the AMMA field experiment in 2006;	ECMWF; AMMA-reanalysis;	May-September, 2006	The ECMWF model showed too much divergence and subsidence over Sahel;
Torn (2010)	Used an ensemble Kalman filter (EnKF) to the Advanced	EnKF coupled to the WRF;	September to October, 2006	The simulations showed that moist processes associated with the cumulus parameterization

	Research version of the Weather Research and Forecasting to generate ensemble analyses and forecasts of a strong AEW during AMMA Campaign;			lead to large error growth longer lead times resulting from moist instability errors that ultimately limit the predictability of larger-scale features;
Meynadier et al., (2010a)	Analyzed the WAM water cycle with the help of NWP models and observational products from AMMA presented in part 1;	ECMWF-IFS	2002-2007	Differences are noted in NWP such as a too southerly ITCZ, i.e. an underestimation of Precipitation in the Sahel, and a surprisingly too strong Evaporation in the same region indicating poor coupling between these too parameters in the models.
Meynadier et al., (2010b)	Investigated the regional-scale water cycle of the WAM in the framework of AMMA, where they investigate in more details the uncertainties and deficiencies evidenced in the re-analyses with the help the AMMA reanalysis and operational models;	ECMWF-IFS, NCEP-GFS, ARPEGE-Tropiques and ERA-AMMA	2002-2007	Several deficiencies are found in the NWP systems. The deficiencies imply the representation of moist processes, the radiation budget, soil moisture analysis, and errors in radiosonde humidity observations;
Fink et al., (2011)	Evaluated the optimal network for Numerical Weather Prediction (NWP) and climate monitoring by performing Observing System Experiments (OSEs);	ECMWF, Météo-France, NCEP, UK Met Office	2006	The model skill to forecast convective activity is poor and the forecasts started from the AMMA re-analyses lost the advantage within the first 24 h over West Africa probably due to the model biases in the short range forecasts;
Bock et al., (2008)	Investigated the atmospheric water cycle at seasonal and intra-seasonal timescales over West Africa for comparison purposes and estimating the uncertainty in NWP models;	NWPs	2002-2007	Large deficiencies are found in all the NWP products;
Marsham et al.,	Compared multiday continental-scale using	UK Met Office	4 August	They showed that large-scale monsoon state in simulations

(2013)	Cascade simulations of the WAM that explicitly resolve moist convection with simulations which parameterize convection;	Unified Model (UM)	2006	with explicit convection differs quite markedly from runs with parameterized convection, even when using the same resolution of 12km;
Beucher et al., (2013)	Evaluated the predictions of the French cloud-resolving model AROME using a set of high-resolution simulations that focus on the well-documented convective period during the AMMA 2006 field experiment (Barthe et al., 2010);	AROME, ARPEGE,	23-28 July, 2006	the ARPEGE model cannot simulate the life cycle of MCSs correctly, the diurnal cycle of precipitation is too strong with a lack of variability from one day to another, and light precipitation events are too numerous in comparison to the strongest ones.
Birch et al., (2014)	Used a suite of model simulations to examine the role of moist convection in the water cycle of the WAM;	UK Met Office Unified Model simulations	Summer, 2006	Significant errors in the water cycle terms occur in the simulations with parameterized convection, associated with the diurnal cycle and the location of the convection;
Stein et al., (2015)	Evaluated the vertical cloud structure of the WAM in simulations of the Met Office Unified Model against CloudSat observations, highlighting model errors in cloud-top height, cloud-type cover, and vertical distribution of radar reflectivity and ice water content;	Met Office Unified Model	2006-2010	Results show that: Firstly, model simulations underestimate the fraction of anvils with cloud top height above 12 km; Secondly, the model consistently detrains mid-level cloud too close to the freezing level; Finally, there is too much low-level cloud cover in all simulations;
Vogel et al., (2017)	Analyze the performance of nine operational global ensemble prediction systems relative to	ECMWF, MF, CMA, JMA, CPTEC, MSC,	2007-2014	All raw ensembles exhibit calibration problems in form of under dispersion and biases, and are unreliable at high probability

	climatology-based forecasts for 1 to 5-day accumulated precipitation based on the monsoon seasons for three regions within northern tropical Africa;	KMA, NCEP, UKMO		of precipitation forecast values;
Stratton et al., (2018)	Described the experimental design of convection-permitting multiyear regional climate simulation using for the first time on an Africa-wide domain;	Met Office Unified Model CP4-Africa R25-Africa	2000-2009	The model lacks the high 3-hourly precipitation events when coarse grained to low resolution;
Roberts et al., (2018)	Investigated whether biases in dust aerosol optical depth over the Sahara and Sahel, known to exist in many global and regional models, can be improved in the UM by using an explicit rather than parameterised formulation of convection,	UM	1 May - 30 September 2011	In all simulations, there is an AOD deficit over the observed central Saharan dust maximum and a high bias in AOD along the west coast. The results also suggest several key problems with the modelled land surface in the UM.

3.5.2 Data needs and gaps

Over African regions, availability of and access to climate datasets is critical for assessment of vulnerability, impacts and adaptation to climate change. The climate information is not widely used or sometime difficult to access to those need it. Probably due to the shrinkage of some observational networks which is occurring depending on the location. Therefore, it is very clear that more effort is highly needed to overcome over this problem of data need and availability. As suggested below, we need the:

High Spatial and Temporal Resolution

An accurate high-resolution precipitation data are needed for improving our understanding of climate, weather, and hydrology. For intense, the studies of Sylla et al., (2013), Gebrechorko et al., (2017) suggested that the quality and consistency of available high temporal and spatial resolution observation datasets should be improved to better understand the response of African climate to global warming.

Length and Timescale

Availability and Requirement of long records of high-resolution continuous timescale rainfall data are needed for many applications. There is a need to improve observational data that satisfy the climate monitoring principles and ensure long-term continuity, and that have the ability to discern small but persistent signal. For attribution studies, datasets would ideally span many decades. Long-term observations are needed within the region.

Real Time Data

A high-resolution near real-time climate data monitoring system is required for West Africa to assist policy makers and water managers and to minimize the detrimental impacts of water and food scarcity (Lamptey, 2008). For intense, study the effects of the observing system on the data measurements in real-time provides data of known quality, and for which temporal and spatial biases can be minimized.

Gap in observational data

Africa is well-known as having inadequate and inefficient observation networks which are very useful for scientific research and decision-making. Despite the extensive progress that has been made in recent years, there are still a number of limitations regarding the assessment of observed products. This may due to the state of the in-situ climate observing system which is seriously inadequate and the number and quality of weather stations in many parts of the continent in decline. In some locations, the climatic data such as time-series data have been interrupting by natural disaster. A particular challenge in Africa is often the lack of sufficiently long-term and spatially representative observed climate data (Gebrechorko et al., 2017). A number of African meteorological agencies are reluctant to make data freely available due to the sharing policies. The collections of national rainfall records are out of date after the crushing, and the absence of reliable records had hampered some African Meteorology Agency’s ability to forecast threats.

Metadata of observed precipitation products

Several precipitation products have been exanimated to ascertain the accuracy of rainfall estimates on various space and timescales within the African continent. Both ground-based (rain gauges) and satellite estimates are used to construct climate database. The conversion of these observations into a coherent gridded climate product (combined) requires considerable data processing (Hofstra et al., 2009, Isotta et al., 2014).

3.6 ADAPTATION AND MITIGATION STRATEGIES IN AFRICA

In the framework of WP1 one of the results is a deep analysis of literature focused on change adaptation and mitigation strategies. The production of combined mapping and clustering of the most frequently cited publications for the period 2006-2016, lead to the following outcomes in relation to knowledge gaps and user needs in adaptation and mitigation strategies to cope climate change.

3.6.1 Knowledge gaps and user needs in adaptation strategies to climate change

The cluster analysis (Fig. 12 and 13, Table10) presents 7 sub-clusters for the adaptation strategies to climate change. In some cases, authors combined adaptation and mitigation at the same level of analysis. The cluster 8 (CL 8) was denote to the mitigation strategies to climate change and was discussed in the section 2.2.

The most of the sample of references (27.7%) dealt with environmental issues and climate change. The most cited references in this sub-cluster are (Flannigan et al. 2006, Lamarque et al. 2011, Hoegh-Guldberg 2011, Adimo et al. 2012). The cluster 2 (CL2) dealt with the regional climate model simulation and adaptation (Jacob et al. 2014, Bindi and Olesen 2011), Brown 2005), Mirza 2011), Refsgaard et al. 2013). In the cluster 3 it was possible to discuss about the user needs and knowledge gaps regarding climate change and socio-ecological vulnerability (Bennett et al., 2016, Eisenack and Stecker 2012, Sissoko et al., 2011, Bruno Soares et al., 2012). With the cluster 4 it was possible to outline the user needs and knowledge gaps in the field of institutional barriers and climate change adaptation (Chaudhury et al., 2013, Huntjens et al., 2010, Luthe et al., 2012, Oberlack 2017). In the cluster 5 the authors discussed about the role of local governments and climate change adaptation (Measham et al., 2011, Beck 2011, Bierbaum et al., 2013, Biesbroek et al., 2013, Ford and King 2015, Lesnikowski et al., 2013). The climate change and the social vulnerability issues were outlined in the cluster 6 (Rygel, O'Sullivan, and Yarnal 2006). The cluster 7 dealt with the concept of climate change perception and adaptation (Connolly-Boutin and Smit 2016, Cooper and Wheeler 2017, Manandhar et al. 2011, Tambo and Abdoulaye 2012).

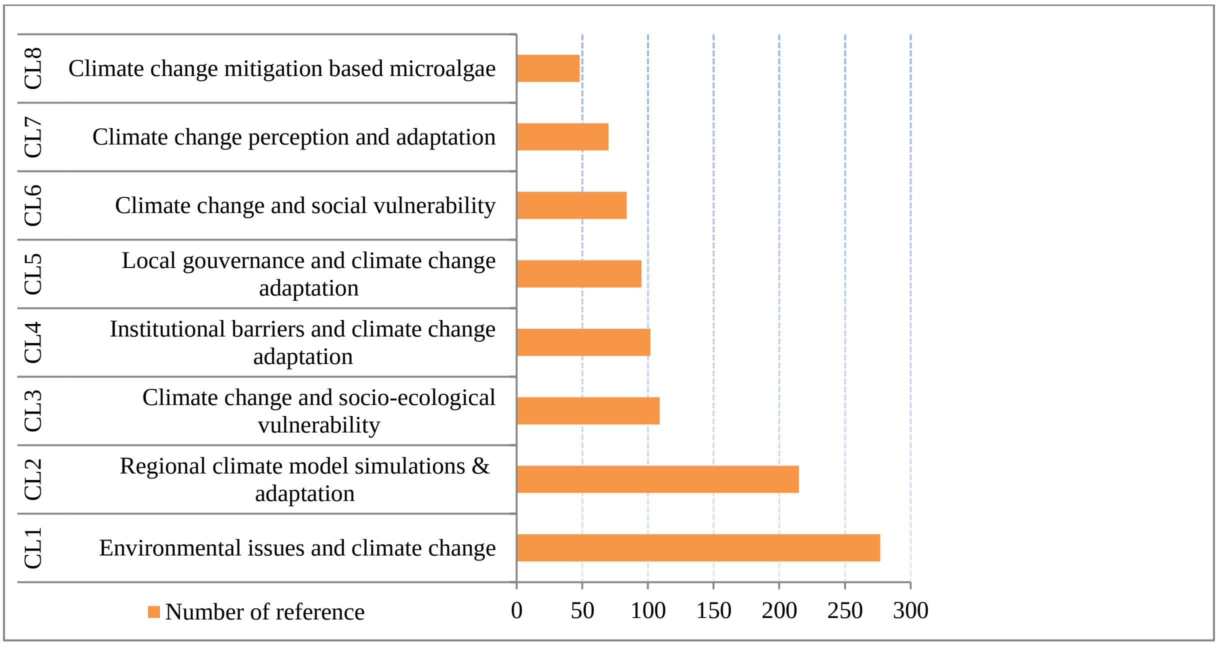


Figure 12. Cluster analysis for climate change adaptation strategies

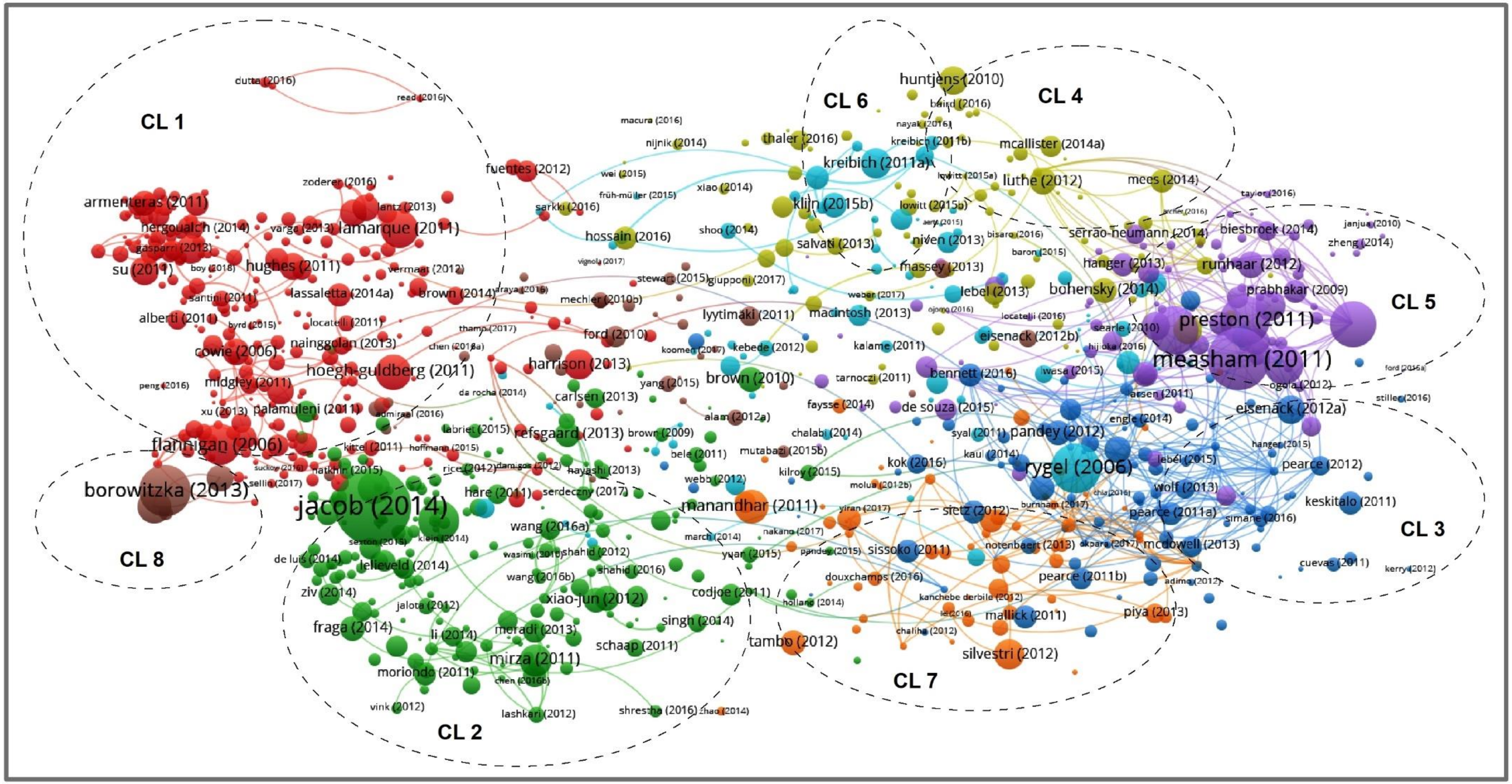


Figure 13 Bibliographic coupling cluster map of Climate Change adaptation strategies

Table 10. Summary of the key findings with regards to user needs and knowledge gaps per cluster in the field of adaptation strategies to climate change

N°	CLUSTER	KEY FINDINGS REGARDING USER NEEDS AND KNOWLEDGE GAPS	OBSERVATIONS / COMMENT
CL 1	Environmental issues and climate change	According to Adimo et al. (2012) for the East African region, there is a need for prioritizing adaptation and mitigation efforts at local level.	The study took place in Africa. Evidence can be proved by stakeholders
		Projections of fire activity for this century can be used to explore options for mitigation and adaptation (Flannigan et al. 2006).	From this developed country example, is there any fire simulation model for Africa or an example of integrated fire research framework developed by (Lavorel et al. 2007)?.
CL 2	Regional climate models simulation and adaptation	Euro-Cordex model is a new high resolution climate change projection models which support adaptations at the regional level in Europe (Jacob et al. 2014).	The way of using CORDEX-Africa to support adaptation for improving food security in Africa is needed
		According to Bindi and Olesen (2011), the most appropriated adaptation strategies to climate change for the European regions are changes in crop species, cultivar, sowing date, fertilization, irrigation, drainage, land allocation and farming system.	Sowing data, irrigation and farming systems seem to be most appropriate for Africa. But evidence must be approved by stakeholders.
CL 3	Climate change and socio-ecological vulnerability	A novel framework that conceptualizes adaptations to climate change as actions (Eisenack and Stecker 2012) is needed. According to the author, the important role of uncertainty and time in adaptation suggest promising lines of research that give more explicit consideration to how stimuli and means unfold in time, along with the perceptions and beliefs of actors.	Evidence can be approved by stakeholders for the African context.
		In its study on "Conceptual elements of climate change vulnerability assessments (VA): a review" Bruno Soares et al. (2012) underlined remaining challenges such as: - The need to better understand how human and environmental systems are coupled and the ways in which they interact (Birkmann, J. and Wisner 2006), - The need to further explore the relationships and links between the key components of vulnerability, - The need to continue developing new ways of integrating - Uncertainty in VA (Kuntz-Duriseti 2008) and policy-making.	In fact, assuming that vulnerability is ahead of adaptation, there is a need for the models on the couple human-environmental systems which will help to improve adaptation. Expertise in the development of such models is very scarce in Africa
		According to Sissoko et al. (2011), in terms of development, priority needs to be given to adaptation and implementation of comprehensive programs on water management and	Evidence can be approved by stakeholders

		irrigation, desertification control, development of alternative sources of energy and the promotion of sustainable agricultural practices by farmers.	
CL4	Institutional barriers and climate change adaptation	According to Oberlack (2017) more coherence and integration of adaptation research are needed if we are to foster learning about the role of institutions in adaptation situations in a cumulative fashion.	We hope there is a need for institutional mapping regarding climate change issues in Africa. Evidence must be approved by stakeholders.
CL 5	Local governance and climate change adaptation	According to Measham et al. (2011) climate adaptation was widely accepted as an important issue for planning conducted by local governments.	Benin case study revealed this evidence. Local governments face the challenge of introducing climate change mitigation strategies into the planning actions.
CL 6	Climate change and social vulnerability	The vulnerability index assessment in developing countries such as African countries is a big challenge because of non-availability of relevant data (Rygel et al. 2006))."	Questionnaire design and introduction to the relevant expert is a key approach for discovering the level of data availability.
CL 7	Climate change perception and adaptation	According to Connolly-Boutin and Smit (2016)), the predominant approach to analyzing climate change and food security in sub-Saharan Africa has been to model the effects of future climate change scenarios on food production. There is a need to go beyond the individual level, and to plan and provide support for appropriate technologies and strategies and in addition considerable efforts should be made to increase the initial likelihood of adoption (Manandhar et al. 2011,Tambo and Abdoulaye 2012).	Evidence can be approved by stakeholders

Resume of keys user needs and knowledge gaps related to climate change adaptation

From the general overview of main keys findings from literature review the essential knowledge gaps and user needs in the field of adaptation strategies to climate change was provided in the table below.

Table 11: Key user needs and knowledge gaps in the field of adaptation strategies and relate authors

N°	KEYS USER NEEDS AND KNOWLEDGE GAPS	AUTHORS
1	There is a need for prioritizing adaptation and mitigation efforts at local level	Adimo et al., 2011; Measham et al., 2011
2	Sowing date is a very important adaptation strategies that must be addressed for the Sudan and Sahel zones of Africa	Bindi et al., 2010
3	In terms of development, priority needs to be given to adaptation and implementation of comprehensive programs on water management and irrigation, desertification control, development of alternative sources of energy and the promotion of sustainable agricultural practices by farmers	Sissoko et al., 2011.
4	The vulnerability index assessment in developing countries such as African countries is a big challenge because of non-availability of relevant data	Rygel et al., 2005; Schneider and Kuntz-Duriseti, 2002.
5	A novel framework that conceptualizes adaptations to climate change as actions is needed.	Eisenack et al., 2012
6	The impact models of climate change do not investigate the practical feasibility of adaptations.	Connolly-Boutin and Smit (2016)

3.6.2 Knowledge gaps and user needs in mitigation strategies to climate change

We will focus our analysis on the clusters 3 to 6 (except 5) and CL 14 to 17. The remaining clusters in the figure 5 belong to the adaptation strategies to climate change.

The most cited reference in the cluster 3 were focus on the greenhouse gas (GHGs) mitigation strategies. The link between published papers in this cluster was very poor with the big distance between references. This assert that the main ideas of the research interest inside the cluster were not really interconnected. The main cited references (Kirschbaum 2006, Huesemann 2006, Peterson 2008, Ravindranath 2007), (Figs. 14 & 15, Table 12) dealt with the concepts related to mitigation, science and technology transfer. In the cluster 6 the literature review (Lehmann et al. 2006, Faaij 2006), reveals the role of bio-char in the mitigation strategies to climate change

In the cluster 14 published paper and most cited references (Gong et al. 2013, Zhou et al. 2014) discussion were related to mitigation-based new energy vehicles in a country like China. This cluster is not currently well related to African context.

The cluster 15 dealt with the climate change mitigation-based microalgae production (Huntley and Redalje 2007, Singh and Ahluwalia 2013, Fon Sing et al. 2013, Kraan 2010, Frank et al. 2013, Borowitzka and Moheimani 2013, Chanakya and Mahapatra 2012, Dupont 2012).

The cluster 17 (Figure 14 & 15) focused on the mitigation strategies and marine ecosystems (Jourdan and Fuentes 2013, Fuentes et al. 2012).

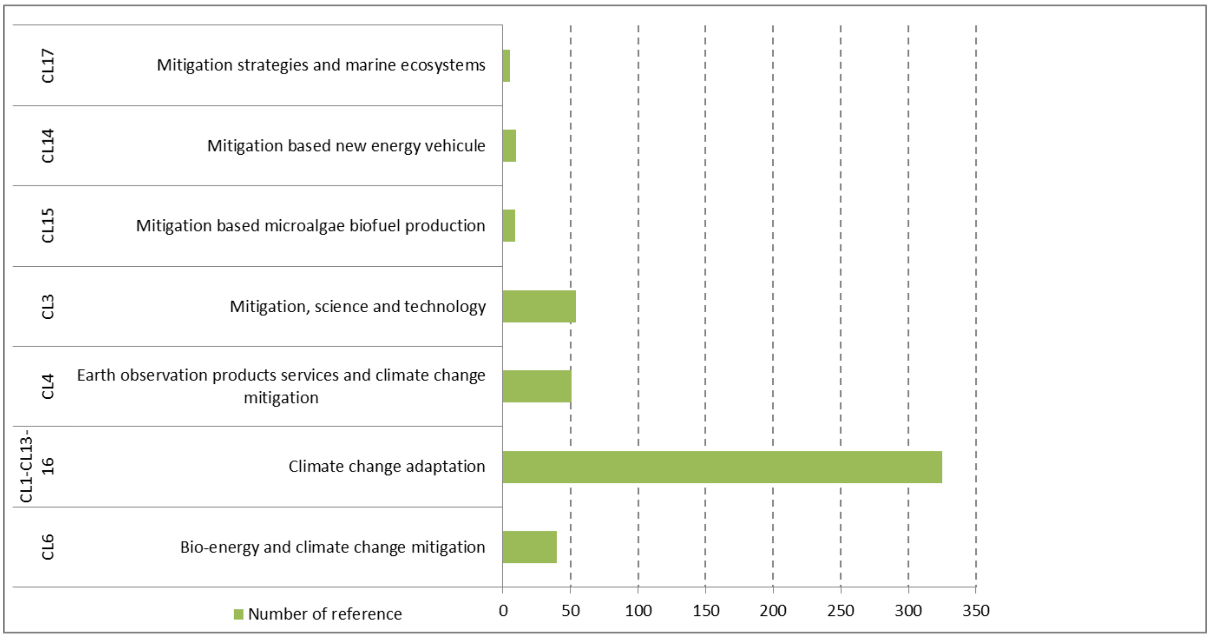


Figure 14. Cluster analysis for climate change mitigation strategies

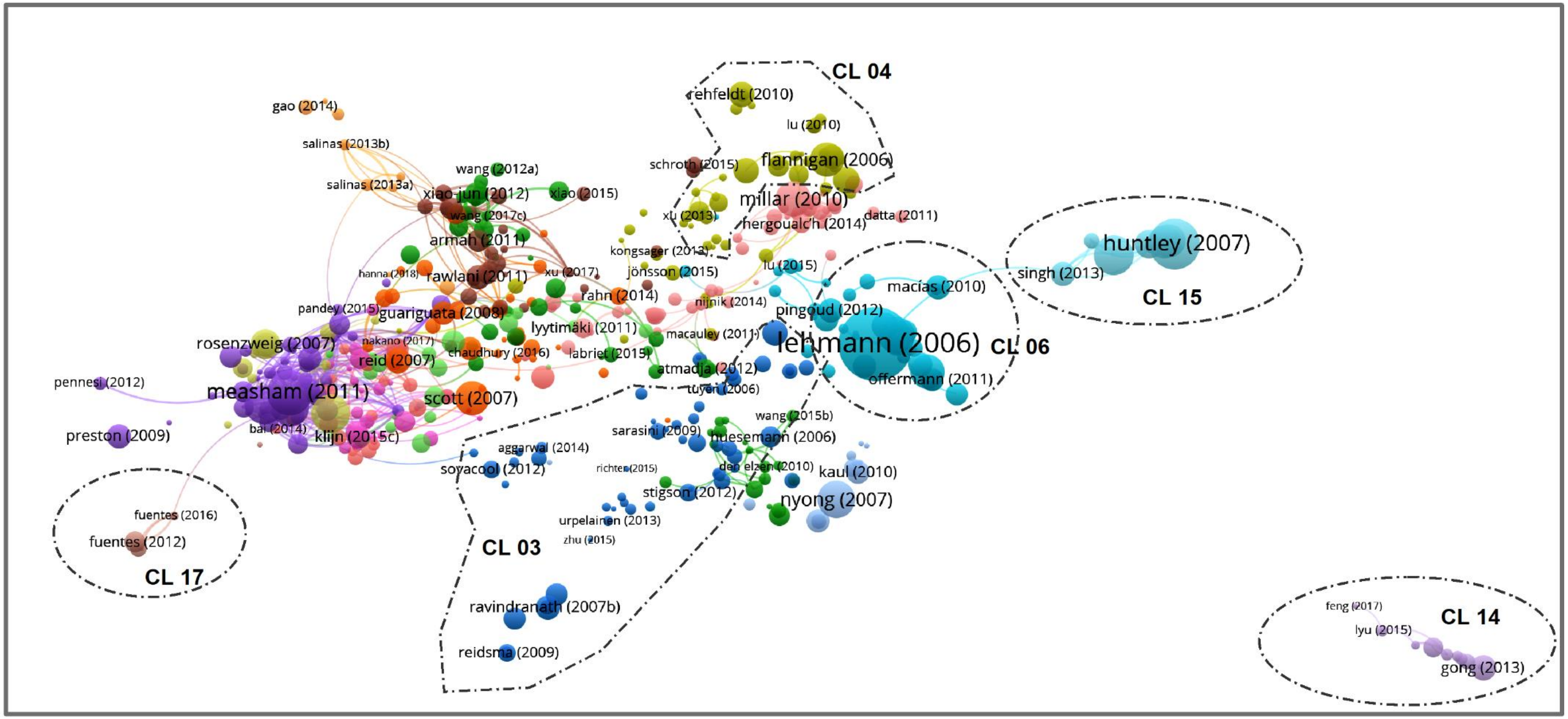


Fig.15. Bibliographic coupling cluster map of Climate Change mitigation strategies

Tableau 12. Summary of the key findings with regards to user needs and knowledge gaps per cluster in the field of mitigation strategies to climate change

N°	CLUSTER	KEY FINDINGS REGARDING USER NEEDS AND KNOWLEDGE GAPS	OBSERVATIONS / COMMENT
1	CL 03	For now, emphasis should more usefully remain firmly on reducing fossil-fuel emission through improving energy efficiency, reducing unnecessary energy usage and generating energy by alternative means such as wind, solar, hydro, or from biofuels (Miko U F Kirschbaum 2006, Michael H Huesemann 2006)**.** What is missing in particular is studies that try to quantify the energy and emission reductions resulting from technology transfer (Peterson 2008a). According to Ravindranath, (2007), there is need for research and field demonstration of synergy between mitigation and adaptation, so that the cost of addressing climate change impacts can be reduced and co-benefits increased.	Evidence can be approved by stakeholders
2	CL04	According to Plummer et al. (2006), there is a need for the integration of observations (Earth observation and in situ), models (diagnostic and predictive), process and manipulative experiments and case studies to close the gaps in knowledge related to the spatial and temporal patterns of carbon stocks and fluxes, particularly over land.	Evidence can be approved by stakeholders
3	CL 06	According to Lehmann et al. (2006b) strategies such as producing bio-char, while producing energy from renewable fuels may offer a potential way forward. In one word, there is a need to replace slash-and-burn to slash-and-char.	Evidence can be approved by stakeholders to prove if this option must be taken ahead mitigation strategies in Africa
		A key issue for bio-energy is that its use should be modernized to fit into a sustainable development path (Faaij 2006b).	Evidence can be approved by stakeholders to prove if this option must be taken ahead mitigation strategies in Africa
4	CL 14	Areas of concern in new energy vehicles include inferior technologies, immature products, and the lack of monitoring and evaluation (Gong et al. 2013, Zhou et al. 2014).	This sector of climate change mitigation, for our point of view should not be a priority for Africa.

5	CL 15	There is currently great interest in microalgae as sources of renewable energy and Biofuels (Borowitzka et al., 2013; Chanakya et al., 2012; DuPont, 2012; Fon Sing et al., 2011 ; Frank et al., 2012 ;) A new appraisal must be focused on CO_2 mitigation and renewable oil from photosynthetic microbes (Huntley et al. 2004).	
6	CL 17	Management strategies are needed to mitigate the impacts of climate change on sea turtle’s terrestrial reproductive phase (Fuentes et al. 2012, Jourdan and Fuentes 2013).	

4 POSSIBLE SOLUTIONS and RECOMMANDATIONS

A comprehensive view of the possible solutions in consideration of the main problems analyzed in this document, are summarized below.

4.1.1 Data

As climate change is prioritized in societal and political agendas, it is reasonable to expect that the need and demand for data and climate information will grow but could critically exceed the ability of producers to establish highly interactive relationships to increase usability. The deficiency in providing reliable data for climate monitoring and spatial coverage of some of the highly elevated areas of Africa is identified as a major gap affecting the detection capacity of impacts resulting from long-term climatic changes. Problems caused by this shortage of data are exacerbated by an uneven distribution of stations, leaving vast areas of central Africa unmonitored and giving Africa the lowest reporting rate of any region in the world (Washington, 2004). Some solutions to data related constrains are listed in Table 13.

Table 13: Data-related problems and proposed solutions

PROBLEMS	SOLUTIONS
DATA USABILITY	TRAINING and TOOLS Even good access tools and high quality data may not guarantee effective use of climate information. Appropriate use requires knowledge within the user community of what information is available and how it might be used. - A facilitated dialogue between scientists and the user community would be of great benefit. - Training the user community to understand, demand and use climate information, as well as training climate scientists to understand the needs of the users (Dinku et al. 2011). - Creation of highly interactive web-based mechanisms (for example, tool-kits) can potentially emulate some of the more desirable aspects of face-to-face interaction allowing for relatively high levels of customization and value-adding (Lemos et al. 2012). INTEROPERABILITY - Data management protocols - SEACRIFOG Collaborative Inventory Tool (Comprehensive data inventory)
DATA SHARING	- Publicly funded RDI[11] outputs at no cost, or at the cost of dissemination (Del.5.2) - “Open Access” approach (free and open access to data) - Transnational cooperation - Improve the connection between existing RI - Data management policy
DATA AVAILABILITY	ACCESS

[11] Research, Development and Innovation outputs

	- Make data, tools and targeted products available through the Internet. - Data repository
DATA RELIABILITY	SPACIAL and TEMPORAL GAPS Spatial gaps are a result of sparse station network, while temporal gaps are due to interrupted observations or lost data due, for example, to communication problems. - Cleaning national climate observations and combining them with satellite proxies could help to fill these gaps. ACCURACY, SPACIAL COVERAGE, TEMPORAL RESOLUTION - Combination of ground-based observations with satellite and/or model information should therefore help to overcome the spatial and temporal gaps in station data while improving the accuracy of the global products (Dinku et al. 2011).

4.1.2 Knowledge and Capacity

The involvement of all relevant stakeholders, both local and international, with different levels of knowledge and capacities will go a long way in supporting Africa's capacity of addressing the various challenges. In particular, the importance of the perceptions, experiences, and knowledge of indigenous peoples has gained prominence in discussions of climate change and adaptation in developing countries and among international development organizations.

Table 14: Knowledge and capacity-related problems and proposed solutions

PROBLEMS	SOLUTIONS
DISSEMINATION	LOCAL, TRADITIONAL AND INDIGENOUS KNOWLEDGE - Creating awareness - Understanding and building upon indigenous knowledge and tools may enhance the design, acceptance, and implementation of climate change adaptation strategies (Codjoe et al., 2013).
CAPACITY BUILDING	- Ad hoc trainings and educational programmes - Capacity building across various levels and stakeholders - Science-policy-end users interface
FUNDING	- Promotion of national and international funding - Involvement of private sector

4.1.3 Infrastructures

The main challenges for the implementation of a consolidated RI for GHG observations across the vast territory of the African continent in the long-term will be the sustainable development of local capacity, the basic infrastructure assurance (e.g. energy supply) and the concept adaptation of already existing RIs in Europe or North America (e.g. ICOS, NEON) to Africa. However, the long-term success of this RI will ultimately rely on its sustained funding. The benefits of a future GHG observation RI in Africa stem from both scientific and socio-economical dimensions. On one hand, standardized in situ observations will contribute to the reduction of uncertainty associated with African and global GHG budgets, and in model development and validation while complementing existing global RIs. On the other hand, the resulting data will be crucial to support the design of early-warning systems as well as suitable mitigation and adaptation strategies that would contribute to food, nutrition and economic security for African populations. Citizens science could emerge as a new kind of low-cost monitoring infrastructure. Investments are needed, e.g. into technologies and equipment and involvement of government subsidies should be promoted.

Table 15: Infrastructures problems and proposed solutions

PROBLEMS	SOLUTIONS
SUSTAINABILITY	- Long term funding - Low cost technologies - Citizen science - Low cost monitoring infrastructures - Development of human capacities - Involvement of private sector

4.1.4 GHG OBSERVATIONS, CARBON STOCKS AND CLIMATE CHANGE MITIGATION

Since mitigation measures can potentially affect the cost, yields and sustainability of food, getting more precise estimates of mitigation and its related effects on food systems is essential to assessing actual trade-offs. Mitigation potentials remain uncertain as most have been estimated through highly aggregated data. At both local and national levels, greenhouse gas budgets for specific farm practices, foods and landscapes are often unavailable, especially in low-income countries. Full accounting of GHGs across all land uses will be necessary but GHG data are often inaccurate, and are not sufficient in terms of spatial coverage with the same accuracy and consequently in terms of available data per emission sector as well as per different ecoregions.

When properly measured, the GHG data should be consolidated, verified/scrutinized in order to ensure their quality giving also the opportunity of a long time series which implies a certain level of sustainability that is usually not achieved with the research projects carried out in Africa. Establishing research infrastructure network across African continent is urgent and deeply needed.

The selection of the observational approaches used will need to be guided by the practitioners (i.e. researchers) and will depend on the available financial and human capacity. Long-term sustainability of the observations does not necessarily entail high temporal resolution measurements. In this instance relatively cheaper methodological approaches could be applied at these stations due to the lower temporal resolution and accuracy requirements, allowing the use of lower cost equipment.

Monitoring stations designed to understand the processes behind GHG budget variability should prioritize accuracy and temporal resolution and should measure a higher number of variables. This type of stations will require higher financial support given the greater costs of equipment and installation and the higher knowledge requirements for long-term operation.

Table 16: GHG observations, carbon stocks and climate change mitigation problems and proposed solutions

PROBLEMS	SOLUTIONS
ACCURACY	- Observation network and data infrastructures supported by remote sensing and EO technology for regional and continental information focused on transboundary data acquisition. - Emission factors more suited for African's reality for more precise reporting process and modelling activities
APPROPRIATE APPROACH TO C AND GHG RESEARCH[12]	- low cost and low technology, - participatory research approach, - network based research
FUNDING	- governmental programmes - international funds - involvement of private sector
INFRASTRUCTURES	- appropriate technology, which utilized low-cost sensors and instrument, - citizen science for low cost monitoring infrastructure form more remote and inaccessible areas. - network approach. - monitoring stations able to prioritize spatial representativeness of African biomes, anthromes, land uses and land covers
TRAINING	- Education and training for local communities focused on sustainable data acquisition practices - Increase awareness of appropriate technology for C and GHG research through educational activities

[12] For a deepening of appropriate approaches for C and GHG in African countries see Annex 2

4.1.5 LAND USE CHANGE IMPLICATIONS ON FOOD SECURITY AND CLIMATE SMART AGRICULTURE

Global food demand is projected to double by the middle of this century, but greenhouse gas emissions from food production must be reduced. Mitigation and adaptation are often regarded as separate, though complementary, objectives in climate policy. Possible trade-offs can, in some cases, be reversed for synergy with the potential to make smallholder farmers in food-insecure regions the main beneficiaries. Appropriate strategies for local communities are urgently needed, targeted actions need to be applicable and suitable on field. Sustainable management of agriculture has a great significance, acknowledged at global level and in this route, climate smart agriculture finds its place being a multilateral "tool" which seeks to guarantee food security of a rapidly growing population aiming at the same time to adapting to a changing climate change while reducing GHG emissions. Promotion of elements of climate smart agricultural practices, such as multi-cropping, agroforestry, shifting crops or organic agriculture would make the difference above all in Sub-Saharan Africa where agriculture needs a more sustainable approach. Stakeholders underlined the importance of Climate Smart Agri-business: maximize production along value chain, adding value to production. Combine the efforts to maximize the production in mixed production systems could lead to increased yield and corresponding revenue.

Spreading good practices for enabling capacity building should consider local social conditions and dynamics as well as traditional believes so lessons learnt could be better shared between farmers and final users in general. Know-how sharing concerning innovative technologies, technology transfer, may be important to introduce farmers to business thinking.

Stakeholders proposed several approaches to promote development in land use change practices having implications on food security, some of the most relevant here below listed.

Table 17: Land use change, food security and CSA problems and proposed solutions

PROBLEMS	SOLUTIONS
FARMERS-SCIENTIST INTERFACE	FARMERS RESPONSIVE RESEARCH - Research should be developed also in response to farming needs. - Improve the assistance to farmers e.g. through the extension offices - Provide assistance with market analyses to cope unpredictable prices - Know-how sharing concerning innovative technologies, technology transfer, introduce farmers to business thinking. - Mobile technology to provide advice to farmers about weather forecast (SMS info) - Improve information sharing and communication with the local farmers
INFRASTRUCTURES	- Promotion of post processed products so that in case of good yield, the price of products will be not decreased and the excess of production will be not spoiled for inadequate storage systems. That could help in diversifying the source of incomes.

	- Implementation of good storage systems for agricultural products and processing systems. - Improvement of irrigation systems and farming facilities
LAND RELATED ISSUES	- Land classification and assessment of land productivity (for avoiding building on fertile land useful for farming) - Secure land tenure
INADEQUATE AGRICULTURAL PRACTICES	- Promotion of good agricultural practices with pilot farming systems and local networking for sharing knowledge - Encouraging crop diversification, promotion of traditional farming and sustainable practices - Need for encouraging people for more efficient production - Employment opportunities (in agriculture people are normally not employed) CLIMATE SMART AGRICULTURE - Formal government support - Promotion of farm level adaptation strategies - Climate Smart Agribusiness
FUNDING	- Providing incentives for the adoption of carbon sequestering agricultural practices to increase crop productivity in the developing world could enhance food security and contribute to climate equity while mitigating climate change (Kahiluoto, H. et al. 2014).
TRAINING AND CAPACITY BUILDING	- Education and assistance for farmers e.g. with regard to technologies or fertilizer application have to be promoted - Communication - Awareness - Know-how sharing

5 CONCLUSIONS

Climate change adaptation and mitigation research has been usually developed distinctly. The mitigation research community focused on limiting cumulative greenhouse gas (GHG) emissions while the adaptation research community, emphasises on locally-focused analysis aimed at minimising the impacts of climate change, especially within the most vulnerable communities. International climate policy has historically developed with a focus on mitigation, nevertheless in recent years increased attention has been placed on adaptation with more targeted financing space, scientific research and political planning actions (Davis-Reddy and Vincent, 2017). There has been a growing consensus within the scientific community that indicates many complex interactions and interdependencies between climate change impacts, adaptation and mitigation (Schwarzinger et al. 2019; Borras & Franco, 2018; Kongsager et al. 2016; Berry et al., 2015; Launder et al. 2015; Harvey et al 2013; van Vuuren et al., 2011). It is increasingly recognised that decisions that are made now could lock in development trajectories for a long time and that there is a need to understand how the mitigation of GHG emissions and climate impacts (and vice versa) interact in the development of policy. Focusing on the synergies, trade-offs and conflicts between mitigation and adaptation, provide an opportunity to bridge the gap responding to priorities to address vulnerability to climate change impacts in developing areas and achieving global commitment in mitigation. Specifically, developmental growth could proceed in a way that will allow countries to become more resilient while maximising opportunities to synergistically reduce emissions and minimise potential trade-offs for mitigation (Davis-Reddy and Vincent, 2017). SEACRIFOG project, could give a contribution in understanding the dynamics behind the low adaptive potential and obstacles in adopting and implementing mitigation and adaptation measures in Africa. Beside the scientific and technical aspects, the solution to most of the constraints could be a comprehensive approach able to consider not only scientific and ecological issues but also socio-economic dynamics (land tenure, urbanization, jobs opportunities, market, prices, investments, etc), linking the scientific community with a wide range of stakeholders (as farmers, local communities, scientist, private sector, decision and policy makers), which may influence the success and the long-term sustainability of RI networks. Science alone is not always enough. It would be important to "demystify science through mediation among scientists, traditional leaders and agriculture extension officers. This could help in facing some of the crucial practical aspects acting as part of the same mechanism, built up to find common and suitable solutions in a participatory approach. A coherent and thorough analysis and prioritization of all these issues can therefore help in developing a range of options suitable for specific 'on field' conditions (at national or regional levels). Among the possible options, the developed countries' approach for an RI network on GHG observations was recognized as not being directly applicable to Africa for different reasons. The most critical reasons are: 1) high costs for implementation and maintenance, 2) lack of qualified personnel and specialized companies, 3) problems with energy supply, 4) accessibility and protection of field sites, and 5) challenging eco-climatic conditions (Lopez Balestreros et al., 2018).

A proper and fruitful collaboration with private sector should be promoted in order to guarantee for certain aspects, a concrete help for more resilient and adaptive society. Above all in Africa, where the high level of investment required to respond meaningfully to adaptation challenges, coupled with the limited public funds being mobilized, private sector can be considered as a tool for resourcing adaptation and driving innovation to foster wider resilience. Facing the multiple challenges of adaptation, mitigation and climate change related causes and consequences, requires a wide range of actors belonging to different sectors, jointly working for a common goal. The efforts for structuring and enabling successful actions could be made possible if there is a multi-stakeholders partnership (MSP) working on the basis of equity, transparency and accountability within partnerships. MSP, could be a potential tool for coordinating action at multiple scales, and for developing more integrated and holistic approaches to addressing barriers within enabling environments. Bringing stakeholders together and increasing the collaboration between different backgrounds, leads to strengthen each sector involved in a holistic manner. Sharing knowledge, expertise, and resources help identifying gaps and addressing significant contributions to a more resilient future (Crick et al. 2017). Dealing about GHG observations and food security related to land use and land use change under a changing climate requires an open-minded and holistic approach able to consider mitigation and adaptation from a different perspective. Mitigation and adaptation strategies have to be wisely developed for a successful planning on the national and international agendas and a more effective implementation at local, national and regional level. Although adaptation more than mitigation was confirmed to be a priority for Africa, it could be important to consider them in a synergistic view. Usually adaptation and mitigation activities tend to be approached separately due to a variety of technical, political, financial, and socioeconomic constraints (Harvey et al., 2014) but the solution to many of the issues raised here could rely on the integration of the two strategies. Addressing the global challenges of climate change, food security, and poverty alleviation requires enhancing the adaptive capacity and mitigation potential of agricultural landscapes across vulnerable areas and particularly in Africa. Prevention and planning could be achieved monitoring GHG (RI needed and assessing emissions in order to properly address the right measures of mitigation and adaptation), investing in capacity building, creating multi-stakeholders networks and approaching problems and solutions in a wider view.

Cooperation between Europe and Africa for scientific research related to GHG observations, land use change and food security, should be finalized not only to filling the gaps and the needs in terms of data (through a network of cooperating infrastructures with common protocols) and of knowledge (by capacity building at different levels) but should also consider these multiple aspects as part of the same common interest, reading from the same page, written in the same language, for achieving common objectives and strengthening collaboration: a common roadmap for leading Africa and EU form being part of the problem to be a proactive part of the solution.

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Atmospheric CO 2 Con- Centration above 1000 Ppm Due to the Continued Use of Fossil Fuels and Unlimited Economic Growth (Table I) Would Result in a Global Temperature Increase of at Least 4 ◦ C (7 ◦ F) by 2100 (Watson et Al ., 2001) Which Is Very Substantial Considering That during the Warmest Period of the Past 200 Million Years the Mean Temper- Ature Was Only 6 – 9 ◦ C (11 – 16 ◦ F) Higher than Today . Even the Most Aggressive Emission Reduction Scenario Published in the IPCC ' s Summary for Policymakers (IPCC , 2001a) Will Result in a Stabilization of the Atmospheric CO 2 Concentration at Approximately 550 Ppm Which Will Increase Global Temperatures by at Least 2 ◦ C (3 . 6 ◦ F) by 2100 (Table I). Additional Warming Is Expected after 2100 Even If the Global CO 2 Concentration Has Been Stabilized at 550 Ppm . The Predicted Range Given That All IPCC Emission Scenarios Including the Most Stringent One (i . e ., Stabilization at 550 Ppm) Would Lead to Significant Global Temperature Increases Which , in Turn , Would Most Likely Cause a Wide Range of Serious Consequences Such as Catastrophic Weather Events , Unprecedented Decreases in Ocean PH (Caldeira And.

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7 Annex 1

Annex 1: List of participant organizations in the three stakeholders' workshops organized by the SEACRIFOG consortium

Organization	Type of organization	Number of participants	Geographical coverage
1st Workshop (Kenya, Nairobi, 31st May 2017) ***Needs and knowledge gaps in the area of LUC, food security, GHGs, and clime-smart agriculture***			
Panafrican Climate Justice Alliance	NGO	2	Regional
Climate Change Department - MEWNR	Governmental institution	2	Kenya
IGAD Climate Prediction and Applications Centre	Research	1	Regional
Kenya Agricultural and Livestock Research Organization	Research	1	Kenya
System for Land-Based Emission Estimation in Kenya	Research	1	Kenya
Low Emission and Climate Resilient Development Project (UNDP)	UN	2	Global
Ministry of Agriculture, Livestock and Fisheries	Governmental institution	1	Kenya
International Development Research Centre	International organization	1	Global
Food and Agriculture Organization of UN - FAO	UN	1	Global
International Livestock Research Institute (ILRI)	SEACRIFOG Project partner	1	Kenya
Euro-Mediterranean Center on Climate Change (CMCC Foundation)	SEACRIFOG Project partner	2	Italy
Univ. Witwatersrand	SEACRIFOG Project partner	1	South Africa
Lund University	SEACRIFOG Project partner	1	Sweden
Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL)	SEACRIFOG Project partner	1	Namibia / Regional
UniResearch	SEACRIFOG Project partner	1	Norway
GEOMAR Kiel	SEACRIFOG Project partner	1	Germany
Univ. Bergen & uniResearch	SEACRIFOG Project	1	Norway

	partner		
University of Nairobi	SEACRIFOG Project partner	1	Kenya
Climate Change, Agriculture and Food Security (CCAFS)/ International Livestock Research Institute (ILRI)	SEACRIFOG Project partner	1	Kenya / Regional
Wondogenet College of Forestry and Natural Resources (WGCF-NR)	SEACRIFOG Project partner	1	Ethiopia
Integrated Carbon Observation System, European Research Infrastructure Consortium (ICOS ERIC)	SEACRIFOG Project partner	2	Finland / Regional
2nd Workshop (Sunyani, Ghana, 16th June 2017) ***"Needs and knowledge gaps in the area of land use, land use change, food security, GHGs, and clime-smart agriculture"***			
University of Energy and Natural Resources (UENR)	Academia	16	Ghana
University of Botswana, Okavango Research Institute	Academia	1	Botswana
Ministry of Food and Agriculture (MOFA)	Governmental Institution	1	Ghana
Department of Agriculture, Sunyani, Ghana	Governmental Institution	3	Ghana
Ghana Space Science and Technology Institute (GSSTI)	Academia	3	Ghana
Regional Centre for Mapping of Resources for Development (RCMRD)	International Organization	2	Kenya / Regional
Office of the Prime minister (OPM)	Governmental Institution	1	Uganda
Local farmers	Farmers	5	Ghana
Survey and Mapping Division of Lands Commission (SMD-LC)	Governmental Institution	1	Ghana
Global Change Research Center of the Czech Academy of Sciences (CzechGlobe)	SEACRIFOG Project partner	2	Czech Republic
Euro-Mediterranean Center on Climate Change (CMCC Foundation)	SEACRIFOG Project partner	1	Italy
Integrated Carbon Observation System, European Research Infrastructure Consortium (ICOS ERIC)	SEACRIFOG Project partner	1	Finland / Regional
West African Science Service Center on Climate Change and Adapted Land Use (WASCAL)	SEACRIFOG Project partner	1	Ghana

3rd Workshop (Lusaka, Zambia, 18th April 2018) ***"Needs and knowledge gaps in the area of land use, land use change, food security, GHGs, and capacity development"***			
University of Zambia	Academia	13	Zambia
University of Botswana	Academia	1	Botswana
Council for Scientific and Industrial Research	Research	1	South Africa
Zambia Youth Water Network	NGO	1	Zambia
Instituto Superior de Ciências da Educação	Academia	1	Angola
University of Namibia	Academia	1	Namibia
Botswana University of Agriculture and Natural Resources	Academia	2	Botswana
Department of National Parks and Wildlife	Governmental Institution	1	Zambia
Climate Service Center Germany (GERICS)	Research	1	Germany
WWF	NGO	1	Zambia
Namibia University of Science and Technology	Academia	1	Namibia
Agostinho Neto University	Academia	1	Angola
National Commission on Research Science and Technology	Governmental Institution	1	Namibia
National Remote Sensing Centre (NRSC)	Governmental Institution	1	Zambia
Copperbelt University	Academia	1	Zambia
University of Jena	Academia	1	Germany
Global Change Research Center of the Czech Academy of Sciences (CzechGlobe)	SEACRIFOG Project partner	2	Czech Republic
Euro-Mediterranean Center on Climate Change (CMCC Foundation)	SEACRIFOG Project partner	1	Italy
Thunen Institute	SEACRIFOG Project partner	1	Germany
Integrated Carbon Observation System, European Research Infrastructure Consortium (ICOS ERIC)	SEACRIFOG Project partner	1	Finland / Regional
Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL)	SEACRIFOG Project partner	2	Namibia / Regional

8 Annex 2

Annex 2: Suggestion for further development and promotion of appropriate approaches for C and GHG in African countries

Developing appropriate approach for C and GHG research	
Low cost and low technology approach	To achieve better accuracy and precision of the results, researchers often look for better materials and method such as advanced instruments and computer software. Accordingly researchers and scientific instrument suppliers are intended to develop their products to meet the desire and demand. While it contributes to improving data quality and quantity the cost of instruments and software often increases and it makes difficult to operate and maintain them without relying on highly skilled man power. Due to the high cost and difficulty in operation and maintenance, African countries often have difficulty to equip them and to conduct research. Consequently, the lack of available data in African countries still remain although data quality and quantity are increased with advancing instrument and software in developed countries. Therefore, efforts are needed to develop not only highly advanced instrument and computer software but also low-tech and low-cost instruments and software, which can be affordable to African countries' researchers and research organizations. In C and GHG research, some studies utilized commercially available inexpensive sensors or instruments or even products for ordinary life use to replace scientifically specified and advanced sensors or instrument (e.g., Shusterman et al., 2018; Collier-Oxandale et al., 2018; Bastviken et al., 2015; Eugster et al., 2012). The approach of utilizing commercially available inexpensive materials often choose reducing or removing atomization and data logging functions and lowering accuracy and precision of measurement. In steady, the approach chooses increasing sampling numbers (ex. manual sampling with increased sampling frequency and sampling replication) to compensate any issue caused by low accuracy and precision of the instruments.
Participatory research approach	The practices involving non-professionals into research activities are often called 'citizen science' or 'participatory research' (e.g., Pocock et al., 2018; Franzoni and Sauermann 2014; Dickinson et al., 2012; Conrad and Hilchey, 2011). Studies demonstrated that collaboration with ordinary citizens has a great potential to enhance C research in African countries (e.g., DeVries et al., 2016; Venter et al., 2015; Theilade et al., 2015;Torres and Skutsch, 2015; Brofeldt et al., 2014). Besides, there have been a number of European-based projects involving citizen participatory initiatives for air quality monitoring with low-cost sensors or monitoring systems (Morawska et al., 2018). Cooper et al. (2014) and Theobald et al. (2015) argued that the contribution of citizen science to global research might be far greater than is readily perceived. Beside these technical aspects, studies found that participatory action research, which local actors could take on expanded roles within the projects (ex. development of research questions and research methodology and data collection and analysis) can contribute to identifying the way building local

	institutional capacity to implement agricultural carbon and climate change adaptation projects (e.g., Shames et al., 2016 and 2013; Mapfumo et al., 2013). The results suggest that citizen science/participatory research approach can be an important for enhancing C and GHG research in African countries.
Networking based research approach	Some studies adopted network based research approach to carry on global change research and they often combined with participatory research approach (e.g., Chandler et al., 2017). Chandler et al. (2017) found that existing network based researches adopting participatory research approach provided large-scale data on species distribution and traits, population abundance, and ecosystem function. A simple parameter measured in a place may not be useful to understand complexity of C and GHG dynamics. However, if the parameter were measured in the different places in a designated time and the collected data were gathered and well organized in a certain format the potential of the data in term of contribution to scientific advance can be far beyond a simple parameter itself. This may well reflect the merit of networking based research.
Their integration	Integration of low cost and low technology, participatory research and networking based research approaches will be an ideal model for further development of an appropriate approach for enhancing C and GHG research. The integration can fill the gap of each approach and also can create synergies. For instance, low cost and low technology approach can have certain uncertainties due to low accuracy and precision of instrument and software. The limitation can be a critical issue to maintain quality of research and contribute to further development of global scientific communities. However, the issue can be resolved by increasing sampling replication and frequency thorough participatory research and networking based research approaches which have power potential to provide useful data, which cannot be easily obtained by individual research. However, the approaches cannot be possible if requires instruments or software for the research are expensive and complicate to operate. In the case, low cost and low technology approach can be appropriate to resolve the concern and support efficiently the participatory research and networking based research approaches.
Promoting appropriate approaches for C and GHG research in African countries	
Technologies	Promoting the technologies by organizing scientific conferences to share identified and developed appropriate technology or the results obtained.
Awareness	Increase awareness of appropriate technology for C and GHG research through educational activities (ex. regular curriculum, science fair, student club activities, etc.) and public mass media.
Funding	Providing funding opportunities for identifying and utilizing appropriate technologies.