International Journal of Development and Sustainability
ISSN: 2186-8662 – www.isdsnet.com/ijds
Volume 12 Number 10 (2023): Pages 452-478
ISDS Article ID: IJDS22111601

Inclusion of climate smart science, technology and innovations (STIs) in the agricultural sector of selected SADC countries

Amon Taruvinga *

Department of Agricultural Economics and Extension, University of Fort Hare, Alice, South Africa

Abstract

High levels of consensus exist with respect to the vulnerability of traditional farming systems to climate change. Public knowledge also suggests that a majority of the rural population in southern Africa derive their livelihoods mainly from traditional agriculture and natural resources. Thus far, climate change affects livelihoods of a majority of the rural population of the southern African region. Literature notes that, climate smart science, technology and innovations (STIs) are possible tools that can be used to mitigate adverse effects of climate change in the agricultural sector. Unfortunately, there is limited empirical evidence to assist with a clear understanding of areas within the agricultural subsectors that require climate smart STIs mainstreaming given the broadness of the agricultural sector. In the interest of promoting evidence-based climate smart STIs mainstreaming in the agricultural sector, this study estimated the level of inclusion of climate smart STIs in seven purposively selected SADC countries (Botswana, Eswatini, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe) using a systems approach. Results revealed a low to moderate inclusion of climate smart STIs in the agricultural sectors of these countries, clearly flagging agricultural innovation systems domains that may be targeted for mainstreaming of climate smart STIs in the agricultural sector at the country level.

Keywords: Climate Smart; Science; Technology and Innovations; Mainstreaming Climate Smart STIs; Agricultural Subsector; Systems Approach

Cite this article as: Taruvinga, A. (2023), "Inclusion of climate smart science, technology and innovations (STIs) in the agricultural sector of selected SADC countries", *International Journal of Development and Sustainability*, Vol. 12 No. 10, pp. 452-478.

* Corresponding author. *E-mail address:* ataruvinga@ufh.ac.za

1. Introduction

African policy makers at national level have been attempting to in-cooperate climate change into their agricultural policies (Knaepen et al., 2015). One of the challenges as noted by Knaepen et al. (2015) has been incoherence between existing climate change and agricultural policies. Of interest to note is the fact that, if research and innovation are properly linked with development initiatives, they boost innovation in agriculture and food systems (Makate et al., 2019). Research and innovation, if properly linked with development initiatives also makes the agricultural system more resilient to climate change and better responsive to development demands (Makate et al., 2019). Science, technology, and innovations (STIs) are therefore believed to be catalysts for sustainable economic and social development as well as carriers of climate smart technologies (UNCTAD, 2018). Thus, the importance of integration of climate smart STIs into national development strategies. Science, technology, and innovations (STIs) are thus far, the developmental pillars that facilitate increased productivity, improve competitiveness, foster growth, and ensure improved livelihoods (FAO, 2017). Against this background, the need therefore arises to build capacity to identify, conceptualize and define specific climate smart STIs indicators that are measurable at all levels for the promotion of climate smart agriculture.

These indicators are expected to address technical and institutional dimensions of science, technological advancements and innovations. The absence of guidelines that facilitate and promote the inclusion of relevant climate smart STIs hampers the adoption of climate smart agriculture. This leads to poor agricultural productivity vulnerable to climate change and shocks (Mabe et al., 2014). This also triggers multiple negative welfare implications (poverty, inequality, food and nutritional insecurity). More especially for the rural citizens of developing countries that highly depend on traditional agriculture and natural resources for their livelihoods (Senadza, 2012). Thus far, it is crucial that countries are supported to identify innovative approaches to stimulate the uptake of climate resilient technology solutions with a view to providing policy recommendations on this issue.

The challenges faced by policymakers towards mainstreaming climate change into agricultural policies leveraging climate smart science, technology and innovation are not surprising given the heterogeneous and dynamic nature of the agricultural system (Läpple et al., 2015). This complexity may be as a result of the structural changes in the global food and agricultural system. Leveraging science, technology and innovation in mainstreaming climate change into agricultural policies is therefore not obvious and straight forward. This is against a background where agricultural innovation is more complex and less linear than once believed (Spielman and Birner, 2008).

Several previous studies have estimated the level of inclusion of STIs in various agricultural subsectors at different levels (Spielman and Birner, 2008; Ariza et al., 2013; Läpple et al., 2015; Nin-Pratt, 2016). A linear approach is dominant in some of these studies focusing more on classical input and output indicators. The hybrid approach used in this study departed from the linear approach and adopted a systems approach. Science, technology, and innovations (STIs) in the agricultural sector was therefore viewed as a complex web of related individuals and organizations with several linkages between components, formal and informal institutions and policies environments that influences this complex web (Spielman and Birner, 2008). This created six strategic agricultural innovation system domains fully representing all the agricultural subsectors and value chain actors. The idea was to holistically scan the level of climate smart STIs inclusion in these domains rather than focusing only on classical measures normally confined in one or two subsystems of the agricultural value chain. The paper therefore presents a systems approach that can be used to track inclusion of climate smart STIs in the agricultural sector. The hybrid systems approach was necessitated by the broadness of the agriculture sector and the fact that climate change and adaptation issues may be embedded in some STIs commonly used in the agricultural sector.

1.1. Problem statement

Measuring innovation in the agricultural sector is a complex task given the broadness of the agricultural system, ever-changing goals and often competing environmental and economic targets (Ariza et al., 2013; Läpple et al., 2015). Although the measurement aspect is complex, a clear understanding of the level of inclusion of climate smart STIs in the agricultural sector is needed to enhance adoption of climate smart agricultural technologies. Literature is however dominated with general innovation measurements skewed in favour of the manufacturing industry at the expense of the agricultural sector (Ariza et al., 2013) and climate smart innovations. The level of inclusion of climate smart STIs in the agricultural sector is therefore highly generalized more often claimed to be low making it very difficult for strategic targeting to enhance climate smart STIs mainstreaming in the agricultural sector especially at national level. In line with previous studies, the study therefore argues that, besides increasing agricultural outputs and yields, policies that transform the agricultural sector to produce outputs that are sensitive to nutrition, responsive to cultural needs, resilient and dynamic to climate shocks and still remain competitive are now more than required (Spielman and Birner, 2008). This therefore calls for a clear understanding of the level of inclusion of climate smart STIs in the agricultural sector at country level to enhance policy makers to identify innovative approaches to stimulate the uptake of climate resilient technology solutions.

1.2. Objectives

To estimate the level of inclusion of climate smart STIs in the agricultural sector of selected SADC countries.

To identify agricultural innovation system domains that can be targeted for mainstreaming of climate smart STIs.

1.3. Expected outcome

The paper thus far seeks to provide a clear understanding of the current level of inclusion of climate smart STIs in the agricultural sectors of the selected countries. This is expected to expose agricultural innovation system domains with low, moderate and high coverage of climate smart STIs. Once climate smart STIs coverage levels are identified at the agricultural innovation system domain level, this is expected to enhance appropriate mainstreaming of climate STIs in the agricultural sector through research, investment and policy support.

2. Conceptual framework

A systems approach was used for this study as the conceptual framework for estimating the level of inclusion of climate smart STIs in the agricultural sector of the selected SADC countries. The systems approach views agricultural innovation as a process with a set of interrelated actors interacting in the production, exchange and use of agriculture related knowledge in processes of socio-economic relevance including the institutional (formal and informal) context that conditions their actions and interactions (Spielman and Birner, 2008). The framework builds on previous linear based approaches like the National Agricultural Research System (NARS) and the Agricultural Knowledge and Information System (AKIS) framework. These previous approaches (NARS & AKIS) focused primarily on the role of education, research and extension in supplying knowledge and technology to farmers (Spielman and Birner, 2008). To the contrary, the Agricultural Innovation System (AIS) conceptual framework includes farmers as part of a complex network of heterogeneous actors engaged on innovation processes along with the formal and informal institutions and policies environments that influences these processes (Spielman and Birner, 2008).

The point of departure from previous approaches is the recognition of innovation as a complex web of related individuals and organizations rather than viewing innovation as a linear sequence of research, development, and dissemination. Figure 1 presents the conceptual framework that captures relevant elements of a national agricultural innovation system including several linkages between components, institutions and policies that creates a supporting environment for innovation (Arnold and Bell, 2001). The following agricultural innovation system domains are suggested as the essential elements of an innovation system following Spielman and Birner (2008): (a) business and enterprise domain, (b) knowledge and education domain and (c) bridging institutions that connects the first two domains. The knowledge and education domain (agricultural research and education) co-create and/or independently generate agricultural knowledge and technologies, while the business and enterprise domain (value chain actors and organizations) use outputs from the knowledge and education domain and innovate independently (Spielman and Birner, 2008). The two domains are connected by the bridging domain (extension, services, and stakeholder platforms) that facilitate transfer of information.

The conceptual framework also includes the frame conditions that impede or enhance innovation (these include public policies of innovation and agriculture, informal institutions that dictate norms, values, rules, cultural attributes, behaviours, perceptions and attitudes that influence the way in which individuals and organizations act and interact within each domain). Lastly, external influencing factors such as linkages to other sectors of the economy (manufacturing and service), international actors, political system and general science and technology policy are also in-cooperated in the framework. The framework therefore suggests that, to identify types of indicators that can be used to measure climate smart agricultural innovation inputs processes and outcomes, a holistic systems approach is required given the spill-over effects of innovation.

From the conceptual framework, the following domains can be assessed their coverage of climate smart STIs using classical and Agricultural Innovation System (AIS) – oriented indicators.

- Climate smart agricultural innovation outcomes and sectoral performance;
- Climate smart agricultural research and education system;
- Climate smart agricultural value chains;
- Climate smart bridging institutions;
- Climate smart agricultural policies, institutions and frame conditions and
- Beyond the system’s borders (climate smart external environment).

Tracking the level of inclusion of climate smart STIs in all the above agricultural innovation system domains should therefore give a fair estimation of how countries' agricultural sectors accommodate climate smart STIs. Of interest to note, is the opportunity to also understand the level of climate smart STIs inclusion at the agricultural innovation system domain level. This can be used as a basis for strategic targeting to enhance climate smart STIs mainstreaming in the agricultural sector.

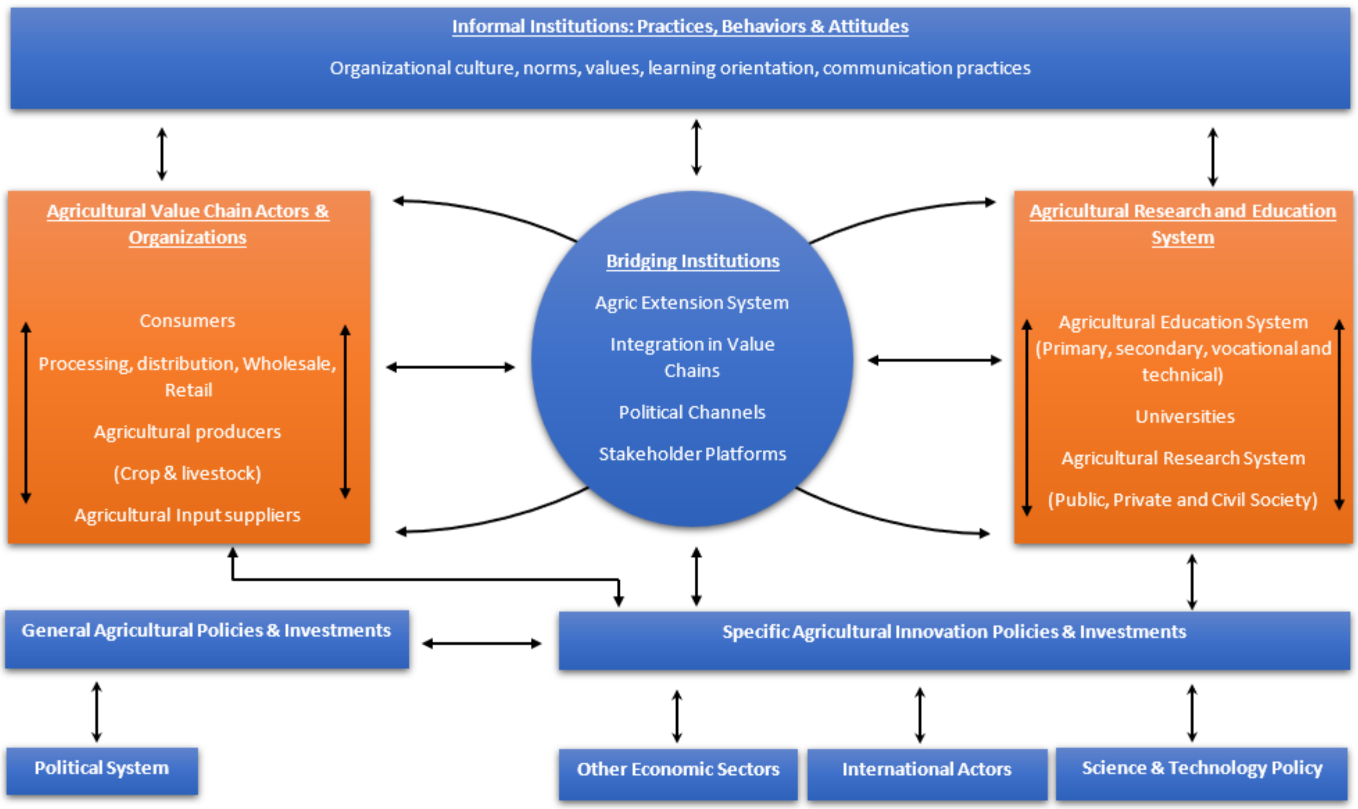

Figure 1. Conceptual Framework for a National Agricultural Innovation System: Source: Modified from Arnold & Bell (2001)

3. Methodology and approach

This section presents the study sites and the methodology that was used for the study. The study was conducted in seven SADC countries (Botswana, Eswatini, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe) purposively selected. The bulk of the agricultural system in these countries is climate dependent (Knaepen et al., 2015). These countries were purposively selected based on high vulnerability of their agricultural sector to climate change (Knaepen et al., 2015; FAO, 2017), availability of data and respondents (in the forms of agricultural experts who were willing to give their expert opinion). Also, these countries were selected given the reliance on agriculture for most of their rural population. Livestock enterprises are major agricultural activities in Botswana and Namibia. The rest of the other countries (Eswatini, Mozambique, Tanzania, Zambia and Zimbabwe) leverage both crops and livestock enterprises. From each country a minimum of four agricultural experts were targeted based on availability and willingness to participate. From a technical point of view the target was to purposively select agricultural experts who have been working in their current position for at least 2 years and have relevant expertise in climate-smart agriculture and innovation. These were also considered from different agricultural value chain actors to accommodate the diverse nature of the agricultural innovation system.

3.1. Analysis

This section presents the approach used for designing climate smart STI indictors for the agricultural sector at national level. Building on previous approaches that focused more on measuring science, technology, and innovation (Nin-Pratt, 2016), a composite measure that incorporates climate smart, science, technology, innovation and country level expert opinions was used (Ariza et al., 2013; Läpple et al., 2015). Thus, climate smart STIs were tracked in the following agricultural innovation system domains as guided by the conceptual framework:

- Climate smart agricultural innovation outcomes and sectoral performance.
- Climate smart agricultural research and education system;
- Climate smart agricultural value chains;
- Climate smart bridging institutions;
- Climate smart agricultural policies, institutions, and frame conditions and
- Beyond the system's borders (climate smart external environment).

The six agricultural innovation system domains broadly cover the concepts of innovation with respect to the agricultural industry that includes creation and/or adoption of innovations, where innovation can be in the form of a product, process, market, organizational and management techniques (Läpple et al., 2015). More importantly the degree to which climate change issues are embedded in these agricultural innovation system domains was the focus. To avoid errors of omission, climate smart STI indicators were measured in two ways as illustrated below following Spielman and Birner (2008).

3.1.1. Classical Indicators

A set of commonly and widely accepted indicators as suggested by literature were used per domain to capture the status of climate smart STIs. With respect to Domain *"1"* – *"agricultural innovation outcomes and sectoral performance"*, these indicators estimated availability of climate smart yield increasing technologies and incentives of farmers to adopt these technologies. With reference to Domain *"2"* – *"agricultural research and education system"*, these indicators measured the strength of the agricultural research and education system and coverage of climate change and adaptation issues for purposes of enhancing individual and organizations' innovative capacity and creation of new products and processes. For Domain *"3"* – *"agricultural value chains"*, the indicators estimated the resilience to climate change, structure, function, and performance of value chain actors thus capturing contribution of technological, organisational and institutional innovation. With respect to Domain *"4"* – *"bridging institutions"*, the indicators estimated the inclusivity of climate change and adaptation issues, diversity and capacity of bridging institutions to connect different domains of an innovation system. Under Domain *"5" – policies institutions and frame conditions*, these indicators estimated the degree of enabling environment for agricultural innovation, climate change and adaptation. Lastly Domain *"6" – beyond the system's borders (external environment)* – these indicators measured the degree of external enabling environment capable of indirectly influencing agricultural innovation, climate change and adaptation.

3.1.2. Agricultural Innovation System (AIS) – Oriented Indicators

Indicators more oriented towards capturing aspects of the innovation system and climate change adaptation such as demand orientation, interactions, relationships, informal institutions and learning processes were also used to complement classical indicators. With respect to Domain *"1" – "agricultural innovation outcomes and sectoral performance"*, these indicators measured processes that underline sectorial performance and the contribution of innovation to performance and resilience to climate change. With reference to Domain *"2" – "agricultural research and education system"*, indicators under this category focused more on the degree of integration or connectedness of climate smart agricultural research and education system. For Domain *"3" – "agricultural value chains"*, indicators under this category focused more on how different value chain arrangements integrate actors and climate smart technologies within a given point along the chain. With respect to Domain *"4" – "bridging institutions"*, the indicators under this category estimated the quality of climate smart linkages between bridging institutions and other system actors. Under Domain *"5" – policies institutions and frame conditions*, these indicators estimated the quality of climate smart policies and their enforcement. Lastly, Domain *"6" – beyond the system's borders (external environment)* – these indicators measure quality of external enabling environment capable of indirectly influencing agricultural innovation and climate change adaptation.

3.1.3. Domain Indicators

This section presents indicators used per each domain for purposes of estimating the level of inclusion of climate smart STIs in the targeted SADC countries' agricultural sector. The indicators were according to the domains set forth in the conceptual framework (Spielman and Birner, 2008). Significant effort was put to make sure that all indicators complied with attributes below following several comparable studies (Spielman and Birner, 2008; Ariza et al., 2013; Läpple et al., 2015):

- Indicators should refer to some measurable phenomenon (both classical and process or throughput indicators);
- Indicators should be relevant to the analysis of climate smart STIs in the target countries' agriculture;
- Indicators should rely on more than a recombination of existing data (published data and data drawn from country level expert opinion across the agricultural subsectors);
- Indicators should be measured using some type of common unit across all categories.

All indicators were then collapsed into an ordered categorical Climate Innovation Indicator Rating Score [(0 to 3): 0 = absent; 1 = poor; 2 = moderate; 3 = good]. For classical indicators, this was benchmarked against expected industry standards (yields based on genetic potential of common varieties and breeds used in the subsector under consideration). A weighted aggregate of these indicators was therefore used to calculate the

Climate Domain Innovation Index (CDII) as detailed in the next section. Appendix 1 summarizes the domain indicators used for this study.

3.1.4. Data sources

The following data sources present a pool of databases that were used as sources of information towards the development and quantification of climate smart STI indicators at country level.

- International and regional online sources:
  - World Bank (https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=ZG)
  - IFPRI (https://www.asti.cgiar.org/)
  - SADC (https://en.unesco.org/news/experts-validate-proposed-science-technology-and-innovation-sti-training-framework-sadc)
- Government sources (Census, government reports);
- Industry sources (market and firm level analysis reports);
- Organizational sources (FAO, UN, CCARDESA reports)
- Expert sources (expert opinion polls) and
- Peer reviewed publication sources (journal articles).

3.1.5. National Climate STI Index for the Agriculture Sector

The six (6) climate smart agricultural innovation domain indicators were considered for the development of a national climate smart STI index (CSTII). The index was based on essential elements of an innovation system domains and several innovation indicators per domain as detailed in the next sections.

3.1.6. Climate Innovation Indicator Score

Each domain had a series of classical and AIS-oriented innovation indicators herein referred to as the Climate Innovation Indicator Score (CIIS) as detailed in Annexure 2. The score per each innovation indicator was calculated as illustrated below:

$$CIIS = \left(\left(\frac{ciiw}{100}\right)\left(\frac{ciirs}{tciirs}\right)\right)$$

Where:

- CIIS = Climate Innovation Indicator Score (ranging 0 to 1);
- ciirs = Climate Innovation Indicator Rating Score ranging from 0 to 3 (0 = absent; 1 = poor; 2 = moderate; 3 = good);
- tciirs = Total Climate Innovation Indicator Rating Score (with a maximum value of 3) and
- ciiw/100 = Climate Innovation Indicator Weight (ranging from 0 – 100% as suggested by country experts).

3.1.7. Climate Domain Innovation Index

The Climate Innovation Indicator Score (CIIS) was used to calculate the Climate Domain Innovation Index (CDII) as illustrated below:

$$CDII = \sum_{ciis=1/n}^{n} \left((ciis_1) + \ldots + (ciis_n)\right)$$

Where:

- CDII = Climate Domain Innovation Index (ranging from 0 to 1);
- n = total number of innovation indicators in the analyzed domain;
- $ciis_1$ = 1st Climate Innovation Indicator Score in the analyzed domain and
- $ciis_n$ = last Climate Innovation Indicator Score in the analyzed domain.

3.1.8. National Climate Science Technology and Innovation Index for the Agriculture Sector

The weighted summation of all the Climate Domain Innovation Indices were used as the proxy climate smart STI Index at country level as illustrated below:

$$CSTII = \sum_{cdii=1/n}^{n} \left(\left(\left(\frac{cdiw}{100}\right)(cdii) \right)_1 + \ldots + \left(\left(\frac{cdiw}{100}\right)(cdii) \right)_n \right)$$

Where:

- CSTII = Climate Science Technology Innovation Index at national level for country x (ranging from 0 to 1);
- n = total number of innovation domains considered in the agricultural sector in country x;
- $cdiw/100_1$ = 1st Climate Domain Indicator Weight (ranging from 0 – 100% as suggested by country experts);
- $cdiw/100_n$ = last Climate Domain Indicator Weight (ranging from 0 – 100% as suggested by country experts);
- $cdii_1$ = 1st Climate Domain Innovation Index for country x (0 – 1) and
- $cdii_n$ = last Climate Domain Innovation Index for country X (0 – 1).

3.2. Interpretation and Implied use of Generated Indices

3.2.1. Climate Domain Innovation Index (CDII)

The CDII is continuous, ranging from 0 to 1 (0% to 100%), where figures close to 1(100%) implied highest level of climate smart STIs inclusion in a specific agricultural innovation system domain and figures close to 0 (0%) implied otherwise. The CDII can also be grouped into an ordered categorical version as follows: low CDII: 0 – 0.5 (0 – 50%): moderate CDII: 0.51 – 0.74 (51% - 74%): good CDII: 0.75 – 1 (75% - 100%). Domains with low, moderate and good climate smart STIs inclusion can therefore be easily identified at national level for strategic targeting through research, investment and policy.

3.2.2. Climate Science Technology Innovation Index (CSTII)

The CSTII is a continuous variable ranging between 0 and 1 (0% and 100%). Figures close to 100% (1) implied the highest level of CSTII inclusion in the agriculture sector of a country and figure close 0% (0) mean otherwise. An ordered categorical version of the CSTII is also possible as follows; low CSTII inclusion: 0 – 0.5 (0 – 50%): moderate CSTI inclusion: 0.51 – 0.74 (51% - 74%): good CSTI inclusion: 0.75 – 1 (75% - 100%). A country's climate smart STIs inclusion in the agricultural sector can therefore be easily identified and compared to other regional countries. At the country level, if a low and moderate CSTII inclusion is estimated, the specific agricultural domains contributing to the low and moderate CSTII inclusion will be revealed for strategic targeting (in this case for improvement). If a good CSTII inclusion is estimated, the specific agricultural domains contributing to the good CSTII inclusion will be revealed for strategic targeting (in this case for maintaining the good performance). Across countries, the CSTII can be used to understand the inclusion of climate smart STIs in the agricultural sectors of different countries from the same region.

3.3. Estimation of agricultural innovation system domains for targeting

To estimate agricultural innovation system domains that can be targeted for mainstreaming of climate smart STIs, correlation and neural multilayer perceptron network analysis were used. The correlation analysis was done to identify the degree to which different domains and the climate science technology innovation index were linearly related. The neural multilayer perceptron analysis was used to complement the correlation analysis in identifying domains with high importance in relation to the climate science technology innovation index. Thus far, domains strongly correlated to the climate smart science technology innovation index (CSTII) were initially selected from the correlation matrix (Appendix 2). Using a neural multilayer perceptron network analysis (Figure 7 and 8), domains with the highest importance were then identified as target domains for mainstreaming climate smart STIs.

4. Results and discussion

The results of the study are presented in this section, focusing on the estimated inclusion of climate smart STIs in the agricultural sector of the selected seven countries and opportunities that can be targeted for mainstreaming climate smart STIs in the agricultural sectors of these countries.

4.1. Distribution of experts consulted from the seven countries

This section presents statistics on country level agricultural experts who were consulted to provide their expert opinion on the level of inclusion of climate smart STIs in the agricultural sectors of their country. Figure 2 presents the distribution of consulted agricultural experts by country.

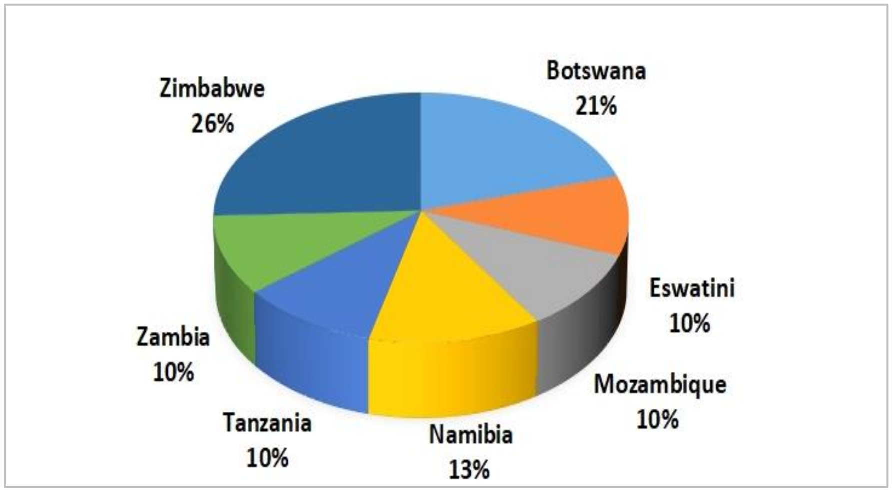

Figure 2. Distribution of consulted agricultural experts by country.

A total of 39 experts were consulted. A majority of the experts consulted were from Zimbabwe (26%), Botswana (21%) and Namibia (13%). A minimum of 4 respondents was targeted for the rest of the other countries as illustrated in Figure 4. Descriptive results further reveal that a majority (51%) of the consulted agricultural experts have been working in their current position for over 10 years, 26% for 5 - 10 years and lastly, 23% for less than 5 years. This therefore suggests that the consulted agricultural experts were highly experienced and knowledgeable of the agricultural issues of their respective countries.

The next section presents the distribution of agricultural experts consulted across different agricultural subsectors as illustrated in Figure 3.

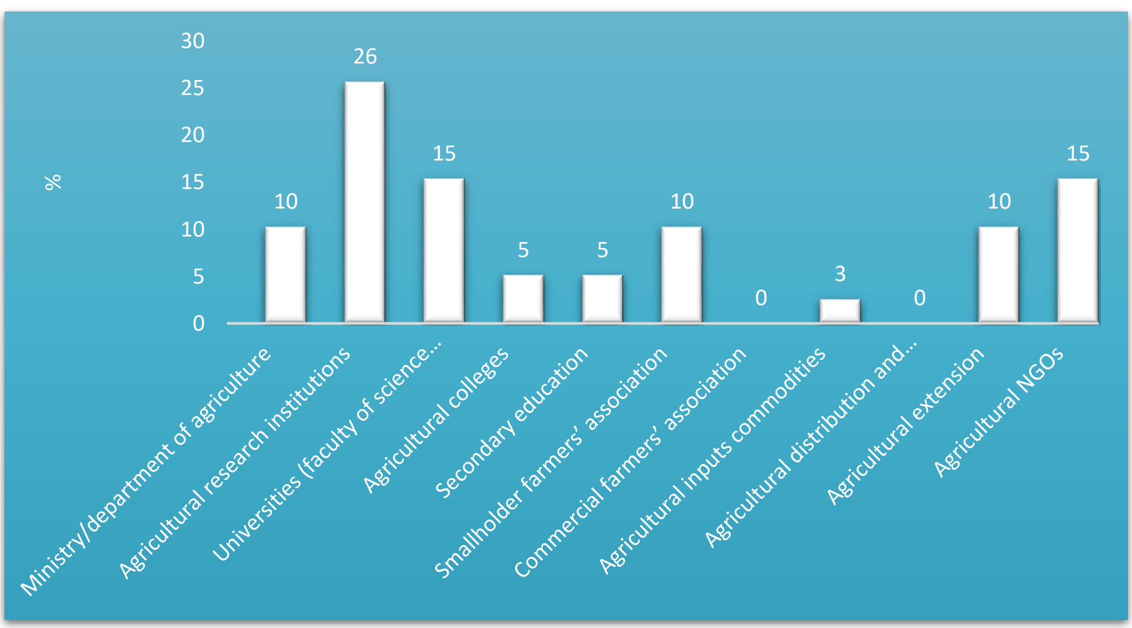

Figure 3. Distribution of consulted country experts across the agricultural subsectors

For purposes of capturing the climate smart agricultural innovation system and bearing in mind that different agricultural stakeholders may perceive climate smart innovation differently, the consulted ccountry experts were purposively selected from different agricultural subsectors (Läpple et al., 2015). These included ministries of agriculture (10%), research institutions (26%), universities (15%), agricultural colleges (5%), secondary education (5%), smallholder farmers associations (10%), commercial farmers associations (0%), agricultural inputs and commodities (3%), agricultural distribution and marketing (0%), agricultural extension (10%) and agricultural NGOs (15%). Experts from commercial farmers' associations and the agricultural distribution and marketing subsectors were not readily available from all countries. At least an expert was consulted from the following subsectors from each of the seven countries: ministries of agriculture, universities, agricultural research institutions, smallholder farmers' associations, agricultural extension and agricultural NGOs.

4.2. Inclusion of climate smart STIs in different agricultural domains

The following domains were used to track the status of inclusion of climate smart STIs in the selected SADC regional countries' agricultural sector (Figure 4):

- Domain 1: Climate smart agricultural innovation outcomes and sectoral performance;
- Domain 2: Climate smart agricultural research and education system;
- Domain 3: Climate smart agricultural value chains;
- Domain 4: Climate smart bridging institutions;
- Domain 5: Climate smart agricultural policies, institutions and frame conditions and
- Domain 6: Beyond the system's borders (climate smart external environment).

Estimates at domain level for all the seven SADC countries revealed a low (≤ 50%) inclusion of climate smart STIs in Domain 1, 2 and 4 and a moderate inclusion in Domain 5 and 6 [with the exception of Mozambique for Domain 5 (0.42) and Eswatini for Domain 6 (0.44)]. Domain 3 also indicated a low inclusion of climate smart STIs for most of the seven countries with the exception of Zimbabwe (0.56) and Tanzania (0.67) as illustrated in Figure 4.

With respect to domain 1, low adoption/trial of climate smart new crop varieties and natural resources management techniques (conservation agriculture, water harvesting, and soil erosion) mainly among the smallholder subsector and to a lesser extent the commercial subsector in other countries were noted as the main areas affecting the low inclusion of climate smart STIs. Low awareness, poor farmer to extension ratio and lack of financial resources to finance climate smart crop varieties and natural resources management techniques were some of reasons highlighted by country experts.

For domain 2 (Climate smart agricultural research and education system), the following areas were flagged as key drivers of the revealed low inclusion of climate smart STIs:

- Low agricultural research and development (R&D) spending allocation on operations, programs and capital investments;
- Low female agricultural researchers with BSc, MSc and PhD qualifications;
- Poor breeding efforts and investment in new climate smart plant varieties and livestock breeds;

- Poor climate smart, science and technology related collaborations between academia and value chain actors;
- Limited agricultural students exchange programmes in advanced training in climate change, science and technology;
- Low inclusion of climate change, science, technology and innovation issues in the research and education system;
- Poor ICT devices and services available to the research and education system;
- Low publication (peer reviewed journals and textbooks) in climate change and innovation by agricultural researchers and;
- Poor agricultural research intensity.

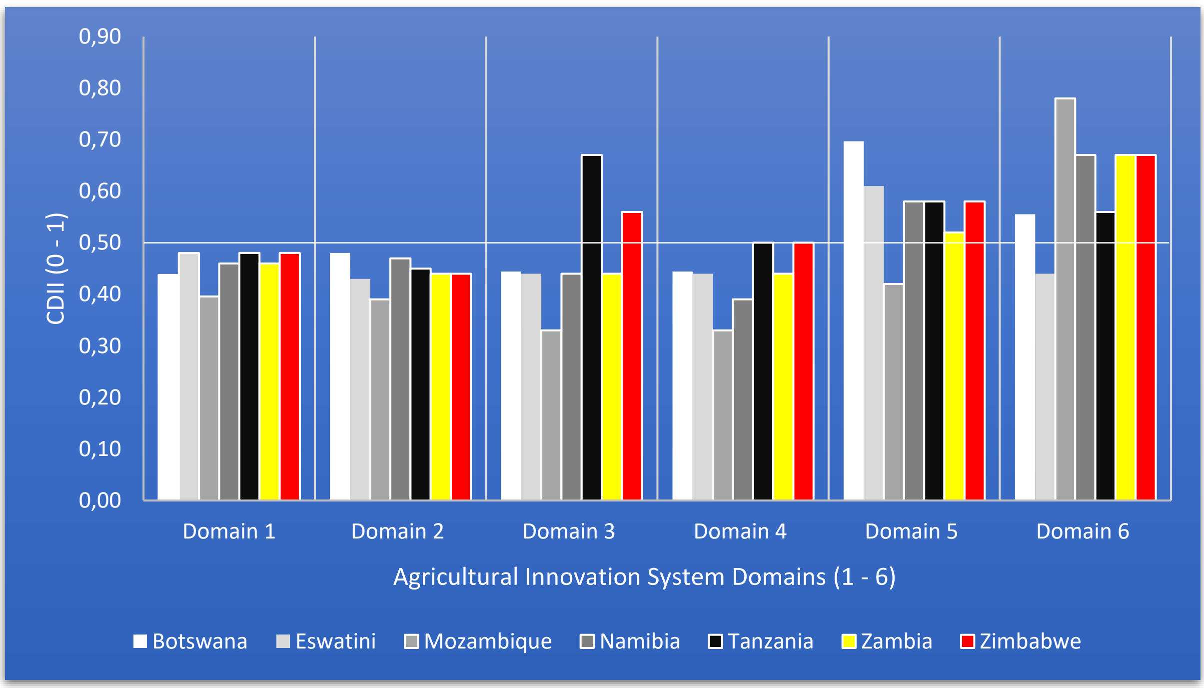

Figure 4. Status of inclusion of climate smart STIs in the SADC regional countries' agricultural sector at domain level

Domain 3 (Climate smart agricultural value chains) mainly noted poor growth rate of agricultural value chains for the seven countries especially among the smallholder subsector and the commercial subsector in some other countries.

Whereas domain 4 [Climate and innovation smart bridging institutions (extension system)] identified the following areas:

- Low level of expenditure on agricultural extension;
- High ratio of farmer to agricultural extension agent;

- Poor qualifications (certificate, diploma, degree) and area of specialisation (crop, animal, and agribusiness) of agricultural extension agents;
- Low frequency of training and skills upgrades related to climate change for agricultural extension agents;
- Poor quality of extension services with respect to enhancing climate smart agriculture and natural resources management and;
- Poor agricultural extension services that are based on climate smart collaborations with other value chain actors.

Lastly, domains 5 and 6 (Climate smart agricultural policies and external enabling environment for agricultural innovation) noted the following areas as potential triggers of low inclusion of climate smart STIs although generally most of the countries were estimated to have a moderate inclusion of climate smart STIs for these two domains:

- Lack of specific agricultural climate change, innovation and investment policies.
- Poor enforcement of specific agricultural policies and regulations that promote climate change, science, technology and innovation in agriculture;
- Very poor rural infrastructure (road networks, communication services - internet, mobile telephone services and access to cell phones);
- High income inequality, poverty and digital illiteracy especially among the rural population negatively affecting the potential to finance, access and use climate smart innovations and;
- Poor linkage between the agricultural subsector and other economic sectors (manufacturing, service) at country level that can boost demand from the agricultural subsector.

4.3. Inclusion of climate smart STIs in the agricultural sector

This section presents the estimated climate science technology innovation index (CSTII) for each of the seven countries (Figure 5) as a proxy measure of the level of inclusion of climate smart STIs in the agricultural sector.

Results indicate an estimated climate STI index of 51% for Botswana possibly driven by its moderate agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure (Domain 5: Index = 0.70) and a moderate climate smart external enabling environment (Domain 6: Index = 0.56). These moderate domains are however negatively affected by Domains 1 (Index = 0.44), 3 (Index = 0.44) and 4 (Index = 0.44) with the lowest indices. Botswana therefore had a moderate (51%) inclusion of climate smart STIs in its agricultural sector.

Estimates for Eswatini reveal an estimated climate STI index of 47% explained by a moderate agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure (Domain 5: Index = 0.61). This is however negatively affected by all other domains with low indices. Against this background, Eswatini had a low (47%) inclusion of climate smart STIs in its agricultural sector.

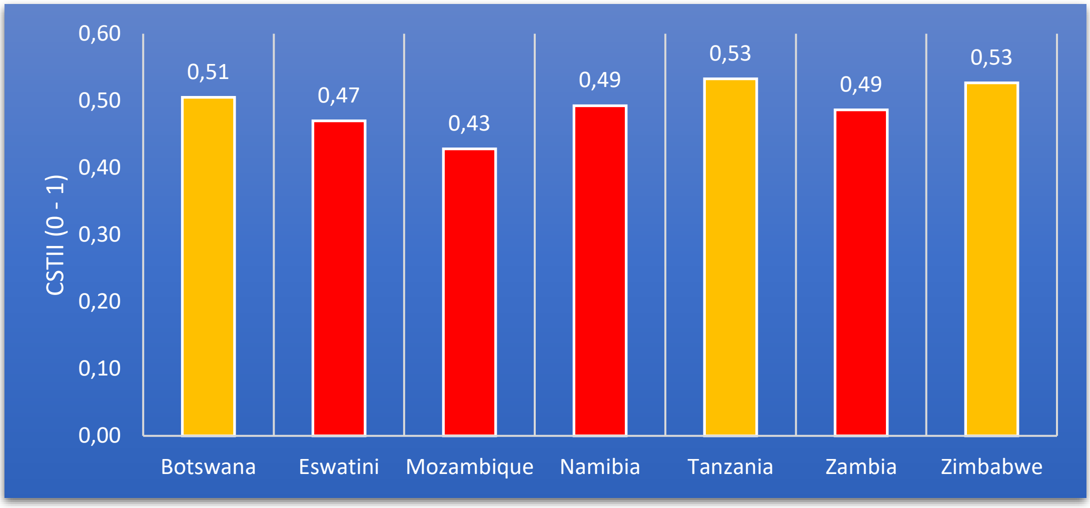

Figure 5. Level of inclusion of climate smart STIs in the SADC regional countries' agricultural sector

Mozambique had an estimated climate STI index of 43%. The country has good climate smart external enabling environment (Domain 6: Index = 0.78). This is however negatively affected by all other domains with low indices especially Domains 3 (Index = 0.33) and 4 (Index = 0.33). Thus far, Mozambique had a low (43%) inclusion of climate smart STIs in its agricultural sector.

Estimates for Namibia reveal an estimated climate STI index of 49% explained by a moderate agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure (Domain 5: Index = 0.52) and a moderate climate smart external enabling environment (Domain 6: Index = 0.67). These are however negatively affected by Domain 4 with the lowest index (0.39). Namibia therefore had a low (49%) inclusion of climate smart STIs in its agricultural sector.

Tanzania had an estimated climate STI index of 53%. The country has moderate climate smart agricultural value chains (Domain 3: Index = 0.67), moderate climate and innovation smart bridging institutions (extension system) (Domain 4: Index = 0.50), moderate agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure (Domain 5: Index = 0.58) and a moderate climate smart external enabling environment (Domain 6: Index = 0.56). This is however negatively affected by Domain 2 with a low index (0.45) and Domain 1 (index = 0.48). Tanzania therefore had a moderate (53%) inclusion of climate smart STIs in its agricultural sector.

Estimates for Zambia indicate an estimated climate STI index of 49% explained by a moderate agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure (Domain 5: Index = 0.52) and a moderate climate smart external enabling environment (Domain 6: Index = 0.67). These are however negatively affected by Domain 2 (index = 0.44) and Domain 3 (index = 0.44) with the lowest indices. Zambia therefore had a low (49%) inclusion of climate smart STIs in its agricultural sector.

Lastly, Zimbabwe had an estimated climate STI index of 53%. The country has moderate climate smart agricultural value chains (Domain 3: Index = 0.56), moderate climate and innovation smart bridging institutions (extension system) (Domain 4: Index = 0.50), moderate agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure (Domain 5: Index = 0.58) and a moderate climate smart external enabling environment (Domain 6: Index = 0.67). This is however negatively affected by Domain 1 with a low index of 0.48 and Domain 2 (index = 0.44). Zimbabwe had therefore a moderate (53%) inclusion of climate smart STIs in its agricultural sector.

4.4. Opportunities for mainstreaming climate smart STIs in the agricultural sector

To enhance mainstreaming of climate smart STIs in the agricultural sectors of the target seven SADC countries, an assessment of the correlation between agricultural innovation system domains and the climate STI index was done as detailed in Appendix 2. Results indicate that the following agricultural innovation system domains have a strong direct positive correlation with climate STI index.

Domain 4: Climate and innovation smart bridging institutions (extension system):

- Firstly, domain 4 has a direct strong positive (coefficient = .903) significant correlation (p-value = .003) with climate STI index.
- Secondly, it also has a strong indirect positive (coefficient = .844) significant correlation (p-value = .009) with climate STI index through domain 1 (Agricultural Innovation Outcomes and Sectoral Performance).
- Thirdly, domain 4 is indirectly positively (coefficient = .880: p-value = .005) correlated with climate STI index through domain 3 (Climate smart agricultural value chains).

Domain 3: Climate smart agricultural value chains:

- Firstly, domain 3 has a direct strong positive (coefficient = .859) significant correlation (p-value = .007) with climate STI index.
- Lastly, domain 3 also has a strong indirect positive (coefficient = .747) significant correlation (p-value = .027) with climate STI index through domain 1 (Agricultural Innovation Outcomes and Sectoral Performance).

Domain 1: Agricultural Innovation Outcomes and Sectoral Performance:

- Domain 1 has a direct strong positive (coefficient = .716) significant correlation (p-value = .035) with climate STI index.

Domain 2: Climate smart agricultural research and education system:

- Domain 2 has a direct strong positive (coefficient = .697) significant correlation (p-value = .041) with climate STI index.

Strategic targeting of the above agricultural innovation system domains (1, 2, 3 and 4) will provide a direct opportunity for mainstreaming climate smart STIs in the agricultural sectors of the seven SADC countries given the strong correlation between these domains and the climate STI index as well as their indirect influence through other domains of the agricultural innovation system.

Indirectly, the following agricultural innovation system domains also can be targeted to promote mainstreaming of climate smart STIs in the agricultural sectors of the seven SADC countries given their facilitation role.

Domain 5: Agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure:

- Domain 5 has a strong indirect positive (coefficient = .846) significant correlation (p-value = .008) with climate STI index through domain 2 (Climate smart agricultural research and education system).

Domain 6: External environment to the agricultural industry:

- Domain 6 has a strong indirect negative (coefficient = -.728) significant correlation (p-value = .032) with climate STI index through domain 5 (Agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure).

4.5. Domain indicators for strategic targeting

This section presents an aggregate assessment of the level of inclusion of climate smart STIs in the selected SADC countries' agricultural subsectors as detailed in Figure 6. This was used for the purpose of identifying domains with low inclusion of climate smart STIs for strategic targeting. Figure 6 presents an aggregate image of all the seven countries in terms of how climate smart STIs are included in the six agricultural innovation system domains. Results reveal low inclusion (< 50%) in domains 1 to 4, moderate inclusion (51-74%) in domains 5 & 6 and an average climate STI index of 49%, which imply low inclusion.

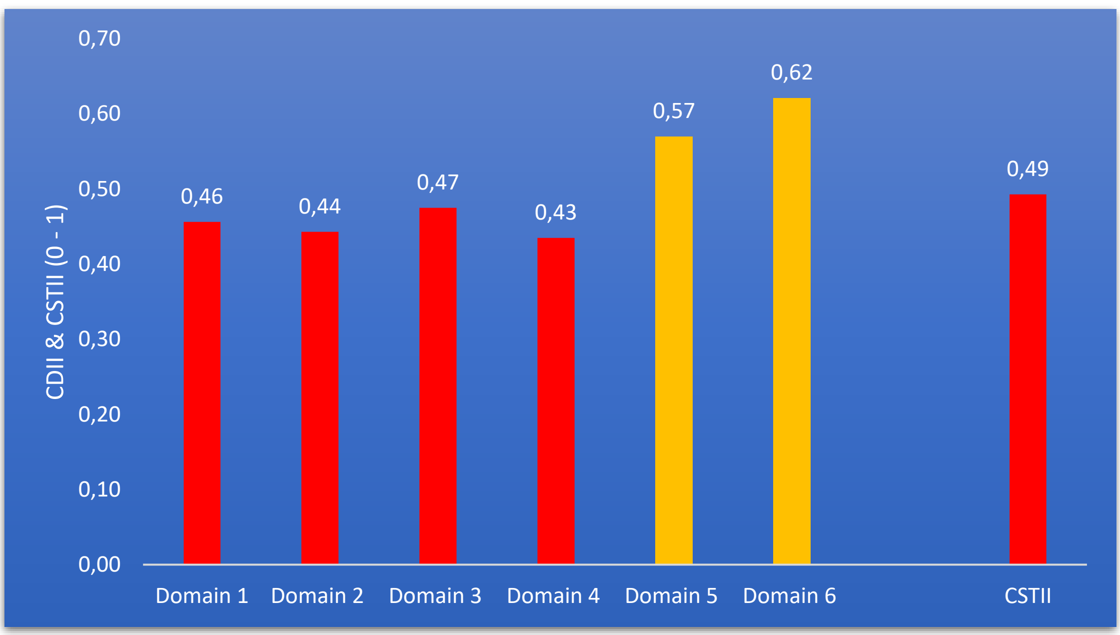

Figure 6. An aggregate summary of the level of inclusion of climate smart STIs in the agricultural sector of the seven countries

These findings suggest that the seven countries' agricultural sector has a low inclusion of climate smart STIs. Their agricultural sector is therefore highly vulnerable to climate change. This may lead to a decrease in agricultural productivity as currently witnessed in a majority of these countries (SADC, 2020). The livelihoods, food and nutritional security of the bulk of the rural population that largely depend on land-based agriculture and natural resources (Senadza, 2012) are likely to be negatively affected. Figures 7 and 8 provide domains that can be targeted for mainstreaming of climate smart STIs in the agricultural sector of the seven countries based on their relative importance to the climate STI index.

Neural multilayer perceptron network regression estimates indicate that, domain 4 has the highest importance (100%), followed by domain 2 (93%), domain 3 (68%) and domain 1 (13%) to enhance mainstreaming of climate smart STIs in the agricultural sector of the seven SADC countries. From an agricultural policy and frame environment point of view, domain 5 has the highest importance (100%) followed by domain 6 (9%) to enhance mainstreaming of climate smart STIs in the agricultural sector of the selected seven SADC countries.

These findings suggests that, for mainstreaming of climate smart STIs in the agricultural sector, the seven SADC countries should focus on developing climate smart bridging institutions (extension system) – domain 4. This calls for a climate smart agricultural research and education system (domain 2) and climate smart agricultural policies, institutions and frame conditions (domain 5) at country level. Domain 2 is expected to drive climate smart science, technology and innovations as well as climate smart graduates that feed into the extension system and line ministries that develop agricultural policies. The interplay of domains; 2, 4 and 5 is therefore expected to positively influence the mainstreaming of climate smart STIs in the agricultural sector of the seven SADC countries.

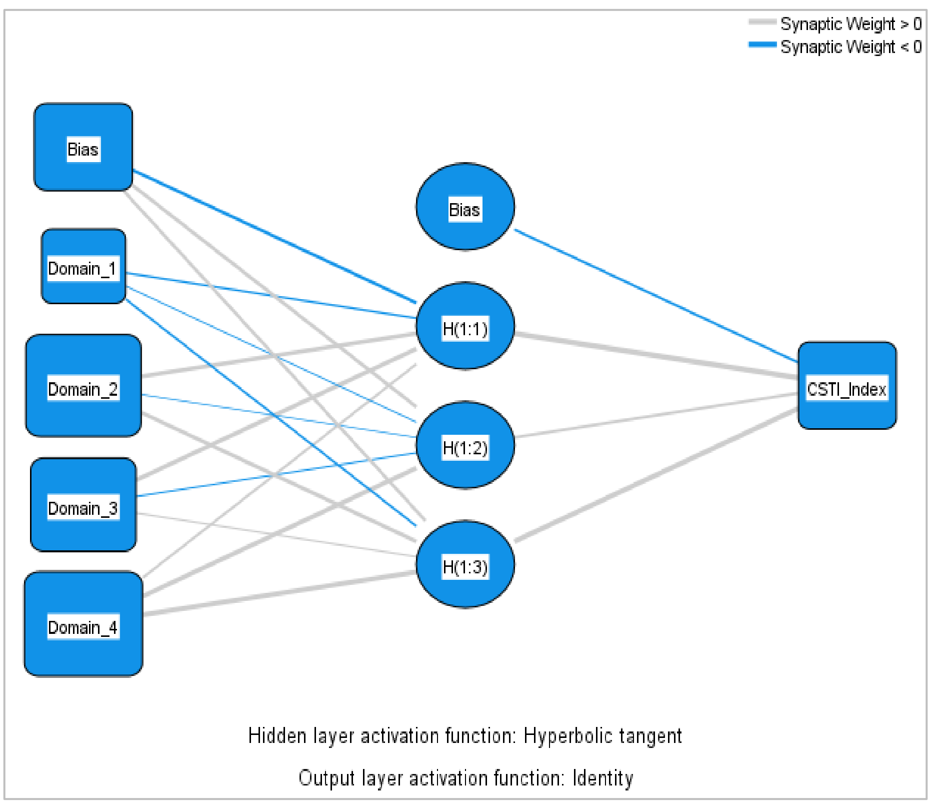

Figure 7. Neural multilayer perceptron network Domain indicators to promote climate STI index (Domain 1 – 4).

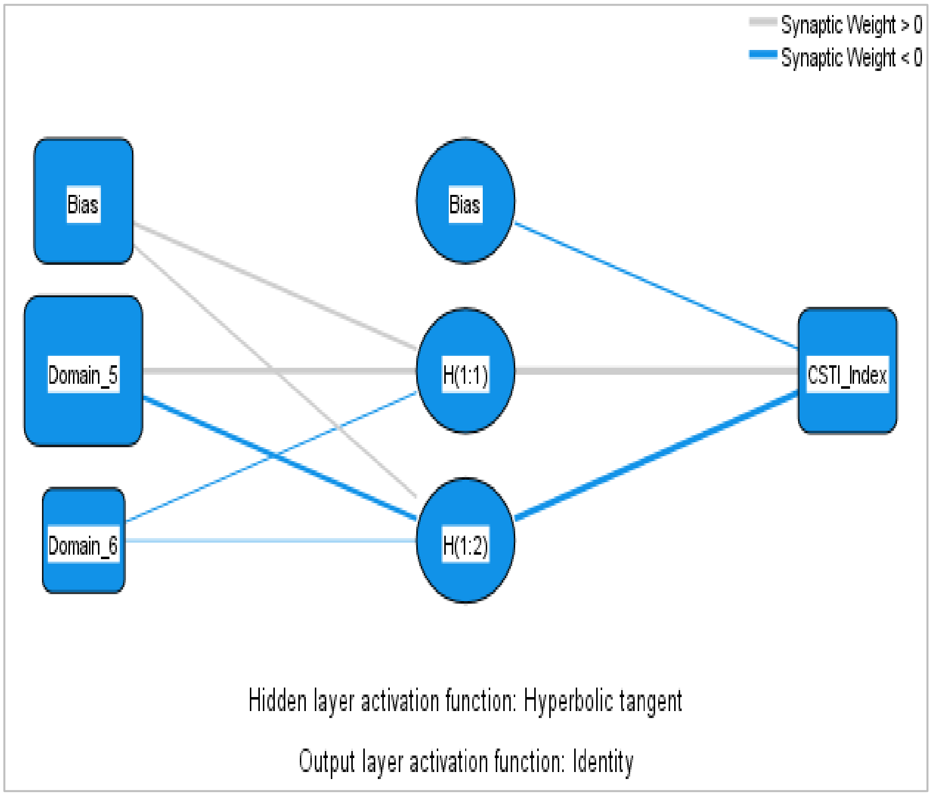

Figure 8. Neural multilayer perceptron network Domain indicators to promote climate STI index (Domain 5 – 6).

5. Conclusions and recommendations

The study estimated the level of inclusion of climate smart STIs in the agricultural sector of selected SADC countries revealing agricultural innovation system domains that can be targeted for mainstreaming of climate smart STIs in these countries. The main findings reveal an overall low inclusion (49%) of climate smart STIs in the agricultural sector of the seven SADC countries. Although Botswana (51%), Tanzania (53%) and Zimbabwe (53%) had a moderate inclusion of climate smart STIs in their agricultural sectors, the rest of the other countries had low inclusion rates (Eswatini: 47%, Mozambique: 43%, Namibia: 49% and Zambia: 49%). At the agricultural innovation system domain level, the results further reveal low inclusion of climate smart STIs in the following domains: agricultural innovation outcomes and sectoral performance (domain 1) 46%, climate smart agricultural research and education system (domain 2) 44%, climate smart agricultural value chains (domain 3) 47%, and climate and innovation smart bridging institutions (extension system) (domain 4) 43%. Guided by the correlation and neural multilayer perceptron network analysis the study suggests a special focus on the agricultural innovation system domains; 2, 4 and 5 for mainstreaming of climate smart STIs in the agricultural sector of these countries. The study findings thus far suggest a low inclusion of climate smart STIs in the agricultural sector of these countries. The low inclusion can be addressed by developing a climate smart agricultural research and education system (domain 2), climate smart bridging institutions (extension system) (domain 4) and climate smart agricultural policies, institutions and frame conditions (domain 5) at the country level. The study therefore concludes that, low inclusion of climate smart STIs in the education and research system of a country (domain 2) creates an agricultural extension system with limited climate smart bridging institutions negatively affecting sharing of climate smart STIs with farmers and other agricultural value chain actors. Graduates from the same education and research system (domain 2) normally have limited capacity to develop climate smart agricultural policies, institutions and frame conditions which promote inclusion of climate smart STIs.

The study therefore makes the following recommendations. A successful strategy for climate smart STIs mainstreaming for the agricultural sector of the seven SADC countries should therefore target creating climate smart agricultural extension, research and education systems (domains 4 & 2). This should be supported by climate smart agricultural policies and enabling frame environment (rural infrastructure) - domain 5.

5.1. Mainstreaming climate smart STIs in the agricultural extension system

5.1.1. Rationale

The agricultural extension system provides bridging institutions critical for linking research with farmers. Thus far, farmers' needs as well as new climate smart STIs require climate smart bridging institutions to enhance smooth flow of information and climate smart technologies in both directions.

Focus for the climate smart extension system (domain 4) should be on:

- Improvement in farmer to extension ratios (through increasing the number of agricultural extension officers employed),
- Improvement in qualifications (certificate, diploma, degree) and area of specialisation (crop, animal, agribusiness) of extension agents (through recruitment of qualified agricultural extension officers),
- Increase in expenditure on agricultural extension (through a deliberate allocation of financial resources towards agricultural extension by the treasury),
- Increase in the frequency of training and skills upgrades related to climate change and digital literacy for agricultural extension agents.

5.2. Mainstreaming climate smart STIs in the education and research system

5.2.1. Rationale

The education and research system produce graduates who eventually work as agricultural extension officers in the agricultural bridging institutions and policy advisors in agricultural ministries and or departments significantly influencing agricultural policies. A climate smart education and research system thus far produce climate smart graduates capable of driving climate smart STIs in the agricultural extension system and climate smart policy advisors in agricultural ministries and or departments.

Focus for the climate smart education and research system (domain 2) should be on:

- Reprioritisation of agricultural R&D spending allocations in favour of operations, programs and capital investments,
- Increase in climate smart crop and livestock breeding efforts,

- Constant review and upgrade of climate STIs coverage in the education system in-line with emerging trends,
- Regional and international student exchange programs in advanced training in climate change, science and technology,
- Regional and in-country science postgraduate training programmes for female agricultural researchers,
- Incentives for publications in climate change and STIs,
- Climate smart, science and technology related collaborations between academia and value chain actors,
- Increase in ICT devices and services available to the research and education system.

5.3. Mainstreaming climate smart STIs in the agricultural policies and enabling frame environment

5.3.1. Rationale

Agricultural policies and the frame environment provide the supporting regulatory framework and the infrastructure to enhance generation and transfer of climate smart STIs within the agricultural sector and associated value chain actors.

Focus for the climate smart agricultural policies and enabling frame environment (domain 5) should be on:

- Effective enforcement of agricultural policies and regulations that promote climate change, science, technology and innovation in agriculture,
- Development of the regional countries' rural infrastructure (road networks, communication services - internet, mobile telephone services and access to cell phones),
- Deliberate allocation of financial resources towards rural infrastructure development by treasury (road networks),
- Tax rebates for mobile network service providers that invest base stations and improve rural internet and mobile telephone services.
- Appropriate linkage between the agricultural subsector and other economic sectors (manufacturing, service and commerce) to boost demand.

5.4. Mainstreaming entities to drive inclusion

At national level, a central national climate change promotion, coordination and monitoring entity hosted in a strategic government department with financial and political influence (presidency or treasury) may be necessary. The entity is expected to drive the mainstreaming of climate STIs and enforcement of policies currently available in most of the seven SADC countries but not enforced. At the regional level, a similar climate change promotion, coordination and monitoring entity within the SADC framework will be necessary to support national entities in the overall mainstreaming of climate smart STIs at the regional level. The regional entity is expected to:

- Generate regional climate smart STIs inclusion standards benchmarking with other regions globally,
- Lobby for research and implementation funding to support climate smart STIs at the national level,
- Promote participation and membership of countries in climate change related treaties, convention and protocols,

- Flagging member countries with low climate smart STIs inclusion in their agricultural sector for possible assistance,
- Co-creation of regional common pool climate smart STIs value chain hubs for easy access by member states.

On a positive note, all countries faired very well on domain 6 (external environment to the agricultural industry) 62%. This presents an opportunity to drive mainstreaming of climate smart STIs in the agricultural sector of these countries, for there exist a good linkage of the agricultural sector and other sectors, good policies on science and technology and political support.

Given the revealed low inclusion of climate smart STIs in the agricultural sector of the seven SADC countries and the overreliance on the vulnerable sector (to climate change) by most of the rural poor from this region, the study calls for mainstreaming of climate smart STIs in the agricultural sector to improve the resilience of the sector, which should boost productivity and significantly address food and nutritional security.

Disclosure statement

No potential conflict of interest was reported by the author.

Acknowledgement

I acknowledge technical contributions from Dr B Podisi and Ms F Magagula from CCARDESA Botswana. This paper was funded as part of the CCARDESA Comprehensive Africa Agriculture Development Programme (CAADP) ex-pillar IV Africa Regional and Subregional Organisations for Research and Innovations Project (CAADP-xP4) under a European Union-funded IFAD Grant Agreement number 2000002983. The CAADP-XP4 programme received funding from the European Commission. Apart from this, the European Commission has no responsibility for the content of this article and the information on it does not necessarily represent the view of the European Commission (EC). The European Union, IFAD and CCARDESA do not accept any responsibility or liability for any use made of the information provided in the article. Lastly, but not least, I acknowledge the support and corporation of experts from the seven countries who provided expert opinion on the level of inclusion of climate smart STIs in the agriculture sector of their countries.

References

Ariza, C., Rugeles, L., Saavedra, D. and Guaitero, B. (2013), "Measuring innovation in agricultural firms: a methodological approach", *Electr. J. Kn. Manage*, Vol. 11, pp. 185-198.

Arnold, E. and Bell, M. (2001), *Some new ideas about research and development*. Copenhagen: Science and Technology Policy Research/Technopolis.

Food and Agricultural Organisation (FAO) (2017), *The future of food and agriculture: Trends and challenges*. FAO, Rome, 2017.

Knaepen, H., Torres, C. and Rampa, F. (2015), *Making agriculture in Africa climate-smart: From continental policies to local practices. European Centre for Development and Policy Management*. Briefing Note, No. 50, November 2015.

Läpple, D., Renwick, A. and Thorne, F. (2015), "Measuring and understanding the drivers of agricultural innovation: Evidence from Ireland", *Food Policy*, Vol. 51, pp. 1-8.

Mabe, F.N., Sienso, G. and Donkoh, S. (2014), "Determinants of choice of climate change adaptation strategies in Northern Ghana", *Research in Applied Economics*, Vol. 6 No. 4, pp. 75-94.

Makate, C., Makate, M., Mango, N. and Siziba, S. (2019), "Increasing resilience of smallholder farmers to climate change through multiple adaptation of proven climate-smart agriculture innovations. Lessons from Southern Africa", *Journal of Environmental Management*, Vol. 231, pp. 858-868.

Nin-Pratt, A. (2016), "Comparing Apples to Apples: A New Indicator of Research and Development Investment Intensity in Agriculture", IFPRI Discussion Paper 01559.

Senadza, B. (2012), "Non-farm income diversification in rural Ghana: Patterns and determinants", *African Development Review*, Vol. 24 No. 3, pp. 233-244.

Southern Africa Development Community (SADC) (2020), *Southern African Development Community (SADC) Regional Indicative Strategic Development Plan (RISDP) 2020–2030*, Gaborone, Botswana, 2020.

Spielman, D.J. and Birner, R. (2008), "How innovative is your agriculture? Using innovation indicators and benchmarks to strengthen national agricultural innovation systems", ARD, World Bank Discussion Paper 41, Washington, DC.

United Nations Conference on Trade and Development (UNCTAD) (2018), "Technology and Innovation Report 2018: Harnessing Frontier Technologies for Sustainable Development", in: United Nations Conference on Trade and Development. UNCTAD/TIR/2018.

Appendix 1: Domain indicators

This section presents indicators used per each domain for purposes of estimating the level of inclusion of relevant climate STI in the SADC region countries' agricultural sector.

Domain 1: Agricultural innovation outcomes and sectoral performance

With reference to Domain 1, the following 16 indicators with equal weights of 6.25% were used.

- Agricultural GDP;
- Total agricultural factor productivity;
- Average yields per hectare of major staple food crops among the commercial agriculture sub-sector;
- Average yields per hectare of major staple food crops among the smallholder agriculture sub-sector;
- Average yields per hectare of major horticultural crops among the commercial agriculture sub-sector;
- Average yields per hectare of major horticultural crops among the smallholder agriculture sub-sector;
- Average yields per hectare of major cash crops among the commercial agriculture sub-sector;
- Average yields per hectare of major cash crops among the smallholder agriculture sub-sector;
- Off-take rate of the commercial livestock sub-sector;
- Off-take rate of the smallholder livestock sub-sector;
- Adoption/trial rate of climate smart new crop varieties among the commercial agriculture sub-sector;
- Adoption/trial rate of climate smart new crop varieties among the smallholder agriculture sub-sector;
- Adoption/trial rate of climate smart livestock breeds among the smallholder agriculture sub-sector;
- adoption/trial rate of climate smart livestock breeds among the commercial agriculture sub-sector;
- adoption/trial rate of climate smart natural resources management techniques (conservation agriculture, water harvesting, soil erosion) among the smallholder agriculture sub-sector and;
- Adoption/trial rate of climate smart natural resources management techniques (conservation agriculture, water harvesting, and soil erosion) among the commercial agriculture sub-sector.

Domain 2: Climate smart agricultural research and education system

For Domain 2, the following 25 indicators with equal weights of 4% were used.

- Agricultural research intensity;
- R&D spending allocation – salaries;
- R&D spending allocation - operations / programs;
- R&D spending allocation - capital investments;
- Level of expenditure on agricultural research and education;
- Level of qualification of agricultural researchers and educators;

- Total agricultural researchers per capita;
- BSc holders (agricultural researchers) per capita;
- MSc holders (agricultural researchers) per capita;
- PhD holders (agricultural researchers) per capita;
- BSc male agricultural researchers per capita;
- BSc female agricultural researchers per capita;
- MSc male agricultural researchers per capita;
- MSc female agricultural researchers per capita;
- PhD male agricultural researchers per capita;
- PhD female agricultural researchers per capita;
- Number of new climate smart plant varieties and livestock breeds released in the past 5 years;
- Level of publication (peer reviewed journals and textbooks) in climate change and innovation by agricultural researchers;
- Level of secondary and tertiary enrolments in agricultural education;
- Level of plant variety protection and patents approval for commercialization in the past 5 years;
- Quality of ICT devices and services available to the research and education system;
- Level of inclusion of climate change, science, technology and innovation issues in the research and education system;
- Share of agricultural students sent abroad for advanced training in climate change, science and technology;
- Extent of agricultural researchers or organizational membership in regional and international research bodies and;
- Quality of climate smart, science and technology related collaborations between academia and value chain actors.

Domain 3: Climate smart agricultural value chains

Domain 3 had 3 indicators with equal weights of 33.33% as summarized below.

- Share and growth rate of agricultural value chains in the country;
- Participation of commercial farmers in climate smart value chains and;
- Participation of smallholder farmers in climate smart value chains.

Domain 4: Climate and innovation smart bridging institutions (extension system)

Six (6) indicators with equal weights of 16.67% were used for Domain 4 as summarized below.

- Ratio of farmers to extension agents;

- Qualifications (certificate, diploma, degree) and area of specialization (crop, animal, agribusiness) of extension agents;
- Frequency of training and skills upgrades related to climate change for agricultural extension agents;
- Quality of extension services with respect to enhancing climate smart agriculture and natural resources management;
- Level of agricultural extension services that are based on climate smart collaborations with other value chain actors and;
- Level of expenditure on agricultural extension.

Domain 5: Agricultural climate change and innovation policies, agricultural informal institutions and rural infrastructure

With regards to Domain 5, the following 11 indicators with equal weights of 9.09% were used as summarized below.

- Digital/ICT literacy level;
- Country's poverty level;
- Country's food and nutritional security at household level;
- Country's income inequality level;
- Country's agricultural climate change, innovation and investment policies;
- Country's membership in regional and international treaties, conventions and protocol related to climate change, science, technology and innovation;
- Level of enforcement of these agricultural policies and regulations that promote climate change, science, technology and innovation in agriculture;
- Country's rural infrastructure status (road networks, communication services - internet, mobile telephone services and access to cell phones);
- Country's share of rural population to total population;
- Country's rural education level? (its ability to equip learners with climate smart agricultural knowledge) and;
- Country's level of openness to indigenous or foreign agricultural climate change and innovation knowledge.

Domain 6: External environment to the agricultural industry

Lastly, Domain 6, had 3 indicators with equal weights of 33.33% as summarized below.

- Political system of a country with respect to supporting climate smart innovative agriculture;
- Country's general policies on science and technology for innovation and;
- Linkage between the agricultural sub-sector and other economic sectors (manufacturing, service).

Appendix 2: Correlation matrix of the Climate STI index and the 6 domains

		CSTI Index	Domain_1	Domain_2	Domain_3	Domain_4	Domain_5	Domain_6
CSTI Index	Pearson Correlation	--						
	N	7						
Domain_1	Pearson Correlation	.716*	--					
	Sig. (1-tailed)	.035						
	N	7	7					
Domain_2	Pearson Correlation	.697*	.439	--				
	Sig. (1-tailed)	.041	.162					
	N	7	7	7				
Domain_3	Pearson Correlation	.859**	.747*	.372	--			
	Sig. (1-tailed)	.007	.027	.206				
	N	7	7	7	7			
Domain_4	Pearson Correlation	.903**	.844**	.448	.880**	--		
	Sig. (1-tailed)	.003	.009	.157	.005			
	N	7	7	7	7	7		
Domain_5	Pearson Correlation	.638	.506	.846**	.358	.560	--	
	Sig. (1-tailed)	.061	.123	.008	.215	.096		
	N	7	7	7	7	7	7	
Domain_6	Pearson Correlation	-.326	-.630	-.400	-.358	-.521	-.728*	--
	Sig. (1-tailed)	.238	.065	.187	.215	.115	.032	
	N	7	7	7	7	7	7	7

*. Correlation is significant at the 0.05 level (1-tailed).

**. Correlation is significant at the 0.01 level (1-tailed).