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TOWARDS CLIMATE-SMART AGRICULTURE IN EGYPT:

Scaling up sustainable practices for enhancing agrifood system resilience and adaptive capacity

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FOREWORD

The civilization of ancient Egypt was grateful to the Nile River and its support to the agriculture as the main profession for the Egyptians who are recognized as one of the first group of people to practice agriculture at a large scale. This was possible because they were able to develop the basin irrigation system. Their farming practices allowed growing variety of crops for consumption, including grains, vegetables and fruits, as well as industrial crops, such as flax and papyrus.

However with the ever increase in population and limited water and arable land in addition to unsustainable agricultural practices, the agrifood system now in Egypt faces serious challenges that has been aggravated by climate change.

Egypt's vision for 2030 recognizes the vulnerability to climate change and identified risk of climate change to natural resources and accordingly to livelihood of the Egyptians. It calls for rational use of the limited water and addressing consequences of the sea level rise on the fertile land of the Northern Delta. The recent Egyptian nationally determined contributions (NDC) promotes water use efficiency, reuse of wastewater, desalinization and rainwater harvesting in addition to changing cultivars to those that are more tolerant to heat, drought and salinity.

Operationalization of the Egypt's vision requires transforming the agri-food system, to be more efficient, more resilient and more sustainable that allow the sector to adapt to climate change and contribute to the reduction of GHG emissions at the sometime enhance resilience of those at the forefront of the impact of climate change. Climate-smart agriculture (CSA) is an approach that helps guide actions to transform agrifood systems towards more productive, sustainable and resilient practices.

This report presents number of major agricultural practices applied by small-scale farmers and private sector as well as national wide programmes implemented by the state; that have been examined and analyzed against the CSA's pillars illustrating role of the public and private sectors, civil society organizations, and women and youth in the adoption CSA practices.

In this context, this publication aims at raising awareness of the relevant stakeholders on the significance of assuming CSA as an approach to address challenges of climate change and support the policy making processes in Egypt to achieve the SDGs. A major objective of this report is scaling up through providing successful models based on scientific investigations for investment in promoting CSA practices contributing to sustainable agrifood systems in Egypt.

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ABBREVIATIONS AND ACRONYMS

CCAFS	Climate Change, Agriculture and Food Security
CEDARE	Centre for Environment and Development for the Arab Region and Europe
CIS	climate information service
CSA	climate-smart agriculture
CSO	civil society organization
EGP	Egyptian pound
FAO	Food and Agriculture Organization of the United Nations
GCF	Green Climate Fund
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
GIZ	German Agency for International Cooperation
ICZM	Integrated coastal zone management
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IPM	integrated pest management
NDC	nationally determined contribution
NENA	Near East and North Africa
NGOs	Non-governmental Organization
RCP	Representative Concentration Pathway
RICCAR	Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region

SADS	Sustainable Agriculture Development Strategy
SDGs	Sustainable Development Goals
SOM	soil organic matter
SPIS	solar pumping irrigation system
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
WFP	World Food Programme
WMO	World Meteorological Organization
WUA	water users' association

Units of measurement

ha	hectare
°C	degree Celsius
kg	kilogram
km	kilometre
mm	millimetre
m^3	cubic metre
ppm	parts per million

Chemical formulae

CO_2	carbon dioxide
NO_2	nitrogen dioxide
CO_2-eq/kWh	CO_2 emission intensity equivalent

EXECUTIVE SUMMARY

Egypt's agrifood system provides livelihoods for more than 57 percent of the population, employing close to 30 percent of the labour force. Though the system is robust, it faces increasing challenges due to population pressure, climate change, and lack of investment in the sector alongside limited water and arable land. Although the proportion of agricultural land increased from 2.9 to 3.85 percent of Egypt's total area between 1970 and 2018, there was a simultaneous decrease in arable land, from 0.24 to 0.07 feddan per person (1 feddan is equal to 0.42 ha). Such rates are attributed to population growth, which jumped from 34.5 million in 1970 to 102.3 million in 2020.

Egypt is particularly vulnerable to climate change. Sea level rise, drought in the North Coast, and extreme heat pose substantial risks to food and livelihood security that depend on agriculture. The heightened frequency and intensity of climate extremes threaten the country's agrifood system, as it depends on these climate-sensitive factors. Assessment has shown an expected decreased yield of main crops due to climate change (Nassr *et al.* 2021).

According to the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, the Nile Delta Region is one of the deltas in the world most vulnerable to climate change due to a combination of intensive water use and seawater intrusion. Not only is the physical loss of land of major concern, but the loss of soil fertility, surface deterioration, groundwater quality, and loss of biodiversity also pose major threats to agriculture. Two critical components of agricultural systems, temperature, and water have been compromised by excessive heat stress and irrigation water shortages, which are affecting the production and diversity of popular crops in Egypt.

The Sustainable Development Strategy (SDS) or Egypt Vision 2030, notes that climate change is an obvious risk to water resources and calls for more sustainable usage of water. It further highlights the need for a climate change adaptation programme for the coastal areas in the Mediterranean Sea, which are impacted by sea level rise. The Egyptian first updated nationally determined contribution (NDC) provided some adaptation measures for agricultural ecosystems, including changing cultivars to those that are more tolerant to heat, salinity, and pests, as adaptation measures for crops. The NDC also promotes water use efficiency, wastewater reuse, desalinization, water quality and pollution management, rainwater harvesting, and water-related ecosystem protection and restoration measures.

Climate-smart agriculture (CSA) is an approach that helps guide actions to transform agrifood systems towards more productive, sustainable and resilient practices. It is organized around three main pillars (FAO, 2013):

1. Sustainably increasing agricultural productivity and incomes.
2. Adapting and building resilience to climate change.
3. Reducing and/or removing greenhouse gas (GHG) emissions, where possible.

CSA approaches have the potential to transform crop and livestock production in a sustainable manner that helps the sector adapt to climate change and contribute to the reduction of GHG emissions. This report examines a number of interventions and practices being implemented by small-scale farmers, private sector stakeholders, and the state, and analyses the extent to which they contribute to the three CSA pillars for building a more sustainable and resilient agrifood system. These practices were identified and documented through field visits to different agroecological areas, representing the major farming systems in Egypt.

The selected CSA practices relate to key agricultural activities: intercropping and crop diversification; minimizing chemical fertilizer use; sustainable and integrated water management; and agricultural waste recycling and management. The report presents the key roles of the public and private sector, civil society organizations (CSOs), and women and youth in the adoption and implementation of CSA practices. It includes also reports on some relevant national programmes being implemented by the Government of Egypt as part of its plan to achieve the Sustainable Development Goals (SDGs).

It is hoped that this report will contribute to raising stakeholder awareness on the value of adopting CSA practices at the policy and technical levels and that it will provide an opportunity for scaling up successful models and attracting investment in programmes and projects contributing to sustainable agrifood systems using the CSA approach.

KEY MESSAGES

- **Climate change**, associated with the intensive use of land and water resources poses a threat to the current farming practices in Egypt, and requires adaptation to the rapidly evolving conditions.
- **The CSA approach and associated practices** offer an opportunity to promote more efficient, inclusive, sustainable, and resilient, agrifood systems.
- **Implementing CSA** varies from place to place according to specific contexts. Developing site-specific solutions depends on a good understanding of farming systems and their exposure and sensitivity to the effects of climate change.
- **Investment in CSA** is attractive to the private sector if institutional, policy and legislation instruments are put in place to facilitate effective involvement.
- **There is a critical need** for gender-based equity programming and education to ensure women farmers in Egypt are properly involved, trained and educated and can benefit from efforts towards developing, sharing and implementing CSA practices.

CHAPTER 1:
Introduction

1.1 Impacts of climate change on the agrifood system: global and regional perspective

Increasing human population, degradation of natural resources and conflicts are threatening global agrifood systems. Climate change poses additional risks to food security and nutrition. **Figure 1** shows the cascading effects of climate change impacts on agricultural ecosystems and agricultural production, related economic and social consequences, and food security and nutrition dimensions (access, availability, stability and utilization) (FAO, 2015).

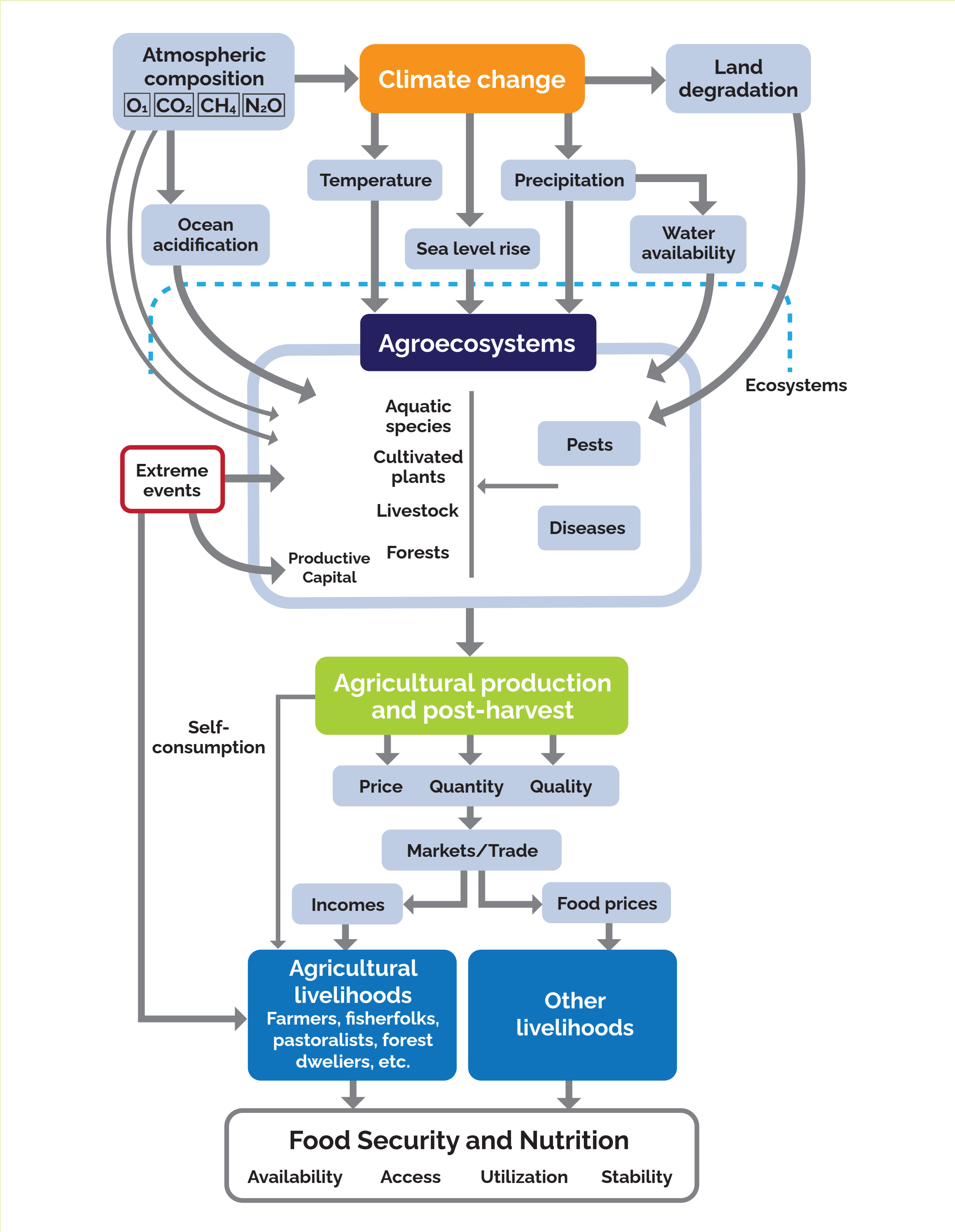
The recent IPCC Sixth Assessment Report (2022) confirms the key findings of previous IPCC reports on the evolution of the climate as well as its main physical effects, such as consequences for land and ocean temperature change, sea level rise, and ocean acidification. It confirms that climate-related extreme events have affected the productivity of agricultural, forestry, and fishery sectors through adverse impacts of droughts, floods, wildfires, and marine heatwaves. These impacts can be seen through fluctuating food availability, increased food prices, threatening food security and nutrition, and the overall well-being of millions.

Further, this recent report (IPCC, 2022) shows that climate change, including increases in frequency and intensity of extreme events, has reduced food and water security, hindering efforts to meet the United Nations' Sustainable Development Goals (SDGs) (high confidence). Although overall global agricultural productivity has increased, climate change has slowed this growth over the past 50 years (medium confidence). The report also predicts that climate change will increasingly put pressure on food production and access, especially in vulnerable regions, undermining food security and nutrition (high confidence). If there are no or low levels of adaptation the increased risks to food security (high confidence) in vulnerable regions will increase from moderate to high between the 1.5 °C and 2 °C rises in global warming (medium confidence).

The Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region report (RICCAR) (ESCWA *et al.*, 2017) shows that the Arab region is expected to experience an average mean increase in temperature of 1.2 °C to 1.9 °C by mid-century (2046-2065) under Representative Concentration Pathway (RCP) 4.5; and from 1.7 °C to 2.6 °C under RCP 8.5, compared with the reference period 1985-2005 (ESCWA *et al.*, 2017). Farming systems in the Near East and North Africa (NENA) are most vulnerable to the impacts of climate change because of their direct dependence on natural resources with high sensitivity to climate change.

Lewis *et al.* (2018) examine the impacts of increasing temperature and variations, and uncertainty of annual precipitation on the different farming systems in the region by the mid-century (2046–2060) in a moderate and worst-case scenario. The report also indicated that climate change trends for the region would result directly in reduced production and productivity for small-scale farmers and indirectly increase the risk of endangered livelihoods for these farmers, especially if there are limited options for diversification. Overall, small-scale farmers in rainfed farming systems are likely to be the most severely impacted by the effects of climate change, while the irrigated farming system that dominates the major areas of Egypt, Iraq and Sudan will see crop yield declines for the major field crops and there is a pressing need to optimize limited water resources.

FIGURE 1. The cascading effects of climate change impacts on food security and nutrition



Source: **FAO.** 2015. *Climate change and food security: risks and responses*. Rome. http://www.fao.org/3/i5188e/i5188e.pdf

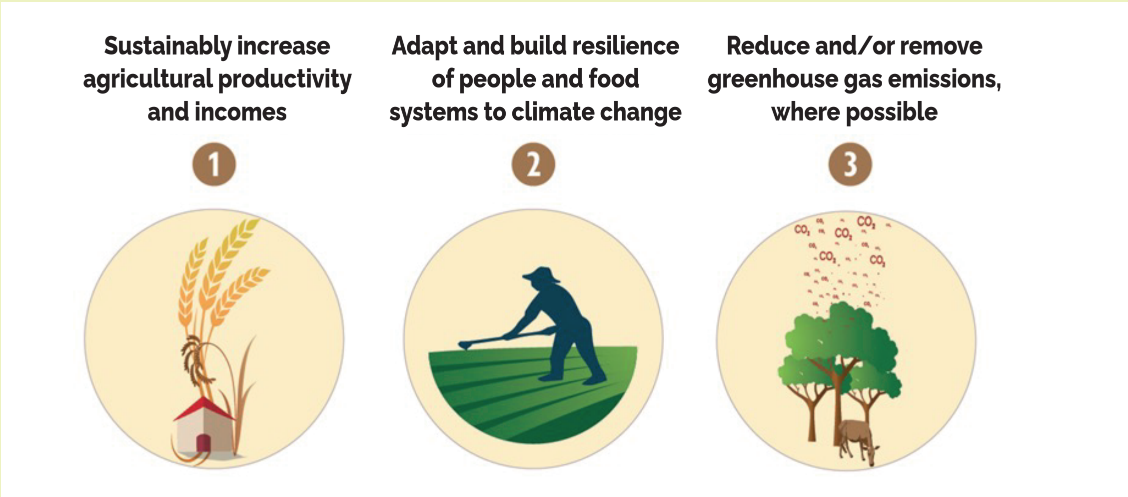
1.2 Concept and definition of climate-smart agriculture

Climate-smart agriculture (CSA) is an approach that helps guide actions to transform agrifood systems towards sustainable and climate-resilient practices. **Figure 2** depicts CSA's three main pillars:

1. Sustainably increasing agricultural productivity and incomes.
2. Adapting and building resilience to climate change.
3. Reducing and/or removing greenhouse gas (GHG) emissions, where possible.

CSA practices are context-specific, depending on and reflecting local socioeconomic, environmental and climate change factors. While it is not expected that every CSA activity in every context will produce positive results across all three pillars, agricultural producers, policymakers and researchers should consider the three pillars when designing a CSA approach to ensure that synergies are maximized and trade-offs minimized (FAO, 2017a). While triple wins between the three pillars are not always possible and trade-offs have to be made, CSA must also consider the overall sustainability of its results in order to achieve truly positive and lasting outcomes in the fight against hunger and climate change. (FAO, 2019).

FIGURE 2. The three pillars of climate-smart agriculture



Source: **FAO.** 2019. *The three pillars of Climate-Smart Agriculture and the Sustainable Development Goals: Synergies and Trade-offs*. Rome. https://www.fao.org/3/ca5778en/ca5778en.pdf

The approach needs to be implemented through five actions:

1. expanding the evidence base for CSA;
2. supporting enabling policy frameworks;
3. strengthening national and local institutions;
4. enhancing financing options;
5. implementing CSA practices at the field level.

Effective adaptation options, together with supportive public policies, enhance food availability and stability and reduce climate risk for food systems while increasing their sustainability (IPCC, 2022).

CSA aims at developing contextual and tailor-made agricultural strategies for more sustainable agrifood systems under climate change. Successful transition to CSA includes the establishment of an inclusive enabling environment that supports the development of suitable institutional arrangements and structures and increased access to credit, insurance, extension and advisory services for small-scale farmers. This enabling environment also supports the development of inclusive processes around stakeholder inclusion and gender equality (FAO, 2022a).

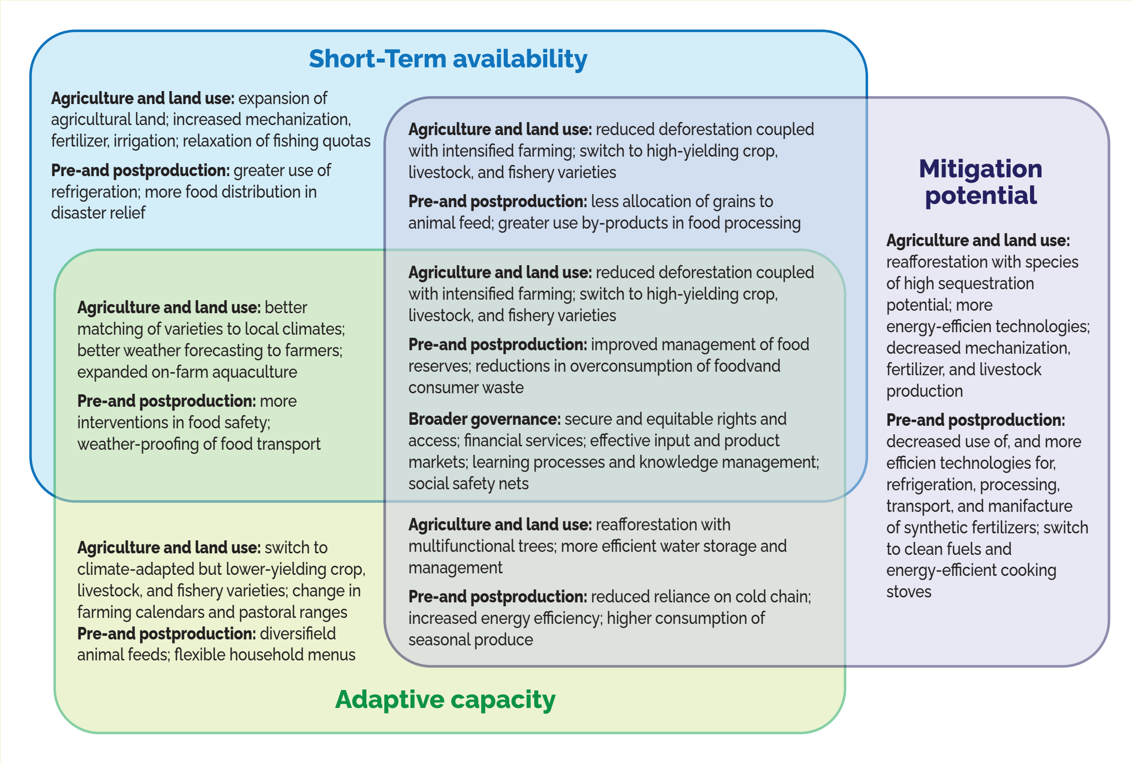
CSA provides tools to support countries in developing the necessary policy and technical and financial means to mainstream climate change concerns into agricultural sectors and provides a basis for operationalizing sustainable agricultural development under changing conditions. CSA is not a single specific agricultural technology or practice that can be universally applied: it is an approach that requires site-specific assessments to identify the appropriate agricultural production technologies and practices (FAO, 2013).

Although the full definition of CSA includes three pillars, and ideally CSA should produce triple-win outcomes (see Figure 3), often it is not possible to achieve all three (FAO, 2016). However, in developing CSA approaches all three objectives must be considered in order to arrive at locally acceptable solutions that reflect local or national priorities. CSA implementation may also require trade-offs, identifying synergies and cost-benefit analysis of different options, based on stakeholder objectives previously identified through participatory approaches.

Lipper *et al.* (2014) also argued that CSA did not imply that every practice in every field would have to contribute to food security, adaptation and mitigation, but that meeting all pillars could be considered in terms of broader regional or national achievements over longer periods of time.

The Climate Change, Agriculture and Food Security (CCAFS) programme of the World Bank has developed a set of "country CSA profiles". These provide a critical stocktake of ongoing and promising CSA practices and of institutional and financial enablers for CSA adoption. The profiles provide information on CSA terminology and how to contextualize it under different country conditions as well as a methodology for establishing a baseline on CSA at the country level (both national and subnational).

FIGURE 3. Synergies and trade-offs for adaptation, mitigation and food security



Source: **Vermeulen, S. J., Campbell, B. & Ingram, J.S.I.** 2012. *Climate change and food systems. Annual Review of Environment and Resources* 37:1, 195-222. https://www.annualreviews.org/doi/10.1146/annurev-environ-020411-130608

1.3 Aim and scope of this report

The objective of this study is to document practices that can balance higher productivity and increased job opportunities with the conservation of the limited natural capital through efficient use of land and water resources while building resilience and contributing to the reduction of GHG emissions.

The study aims to:

1. Identify and document sustainable agricultural practices at both national and local levels.
2. Assess the potential for scaling up successful practices.
3. Identify the gaps to be addressed in the development and implementation of such projects

These practices are assessed for their contribution to the CSA pillars and how they address local challenges.

Data and information were collected across the three main agroecological regions in the country:

1. The Old Lands in Upper Egypt and Nile Delta: Luxor Governorate and Qalubiya Governorate.
2. The New Lands: El Kharga Oasis and a private farm in Ahmed Orabi Settlement.
3. The area under rainfed agriculture: Matrouh Governorate.

The Old Lands

Eighty-five percent of small farms are located in Egypt's Old Lands (Kassim *et al.*, 2018). About 50 percent of these farm plots are less than one feddan (or 0.42 ha) in size, with the remaining being between one and five feddan (0.42 to 2.1 ha). Egypt's agricultural "Old Lands" are highly fertile and depend mainly on the Nile as their main water source for irrigation.

Radwan *et al* (2019) used the land use/land cover maps from 1992 to 2015 to monitor changes in the Nile Delta and quantify the rates and types of transitions. The results show that 74,600 hectares of fertile agricultural land in the Nile Delta (Old Lands) was lost to urban expansion over the 24-year period whilst 206,100 hectares of desert land was converted to agricultural land (New Lands).

It has been estimated that only 5.4 percent of land resources at present in Egypt are considered excellent in quality, while about 40 percent are of poor quality due to the development of sodicit[1]y and salinity constraints. About 2.4 million feddan of the irrigated agricultural land in Egypt suffer from problems of waterlogging, salinization, and sodicity. In the northern central part of the Nile Delta, there is an abundance of salt-affected soils (Negm *et al.*, 2017) due to poor drainage and intrusion of seawater (El-Ramady *et al.*, 2019).

Luxor Governorate in Upper Egypt and private farm in Qalubiya Governorate in the Nile Delta were selected as the two sites in the Old Lands.

- **Luxor Governorate:** as a major governorate of Upper Egypt, Luxor is located on the alluvial plains which include the cultivated area occupying the central part of the Nile Valley and the older reclaimed plain along the valley fringes. The study area is characterized by arid and desert conditions and its climate is varied during the year (EEAA, 2016). Sugar cane is the main crop in the area, with maize as summer crop and usual winter crops such as clover, wheat and broad beans.
- **Qaloubya Governorate:** the site is a typical Nile Delta village with heavy clay soil irrigated by Nile water. The farm area is about 15 feddan and produces a variety of field crops, including corn, broad beans, beans, pepper, eggplants, and cabbage and a variety of fruit trees including banana, grapes, olives, and citrus.

The New Land

The New Lands constitute about 15 percent of the cropped area in Egypt and include both small farms and large commercial farms (Kassim *et al.*, 2018). The New Lands are less fertile than the Old Land, with less water availability and lower productivity. They are found in the western Nile Delta, including El-Tahrir, Maryout, and Nubaria projects as well as the New Valley Governorate, with the Oasis of Kharga, Dakhla and Farafra.

Chemical fertilizers are ubiquitous in these regions, as a response to the increasingly poor soil quality and the original poor fertility of the newly reclaimed desert. Elrys *et al.* (2019) reported that the rate of nitrogen fertilizer application has increased from 136 kg (1961-1970) to 307 kg nitrogen/ha/year (2010-2016), with about 97.5 percent applied to maize, rice, and wheat crops. However, nitrogen use efficiency is also decreasing, from 71 percent in the 1960s to 44 percent during 2010-2016.

1 Sodicity refers specifically to the amount of sodium present in irrigation water. Irrigating with water that has excess amounts of sodium can adversely impact soil structure, making plant growth difficult.

The two sites in the New Lands are:

- **The El Kharga Oasis:** the New Valley Governorate in the Western Desert faces agricultural water scarcity due to a lack of irrigation water, high levels of water and soil salinity, poor agricultural drainage, and the negative impacts of sand creep on irrigation canals and agricultural lands. In order to address some of these challenges, the Food and Agriculture Organization of the United Nations (FAO), in partnership with the Desert Research centre, is implementing a Global Environment Facility (GEF) funded project "Sustainable management of Kharga oasis agricultural ecosystems in the New Valley Governorate."
- **Aquaponics Farm, Ahmed Orabi Settlement:** the site is a non-traditional farming system using greenhouses to grow high-value fish and vegetables together in a soilless agriculture system (aquaponics). Aquaponics provides an opportunity to address many of the problems frequently encountered in farming methods that require soil and often use different agrochemicals to maximize the benefits of each unit of water.

The land under rainfed agriculture

Matrouh governorate was selected to represent the rainfed agriculture area of the North Coast. Rainfed agriculture is the major activity of the Bedonie (the local community of Matrouh), where figs, olives, pomegranates, and nuts are grown on large acreages. However, the low yields of this area are due to erratic and variable rainfall, with amounts ranging from 80 to 280 mm/year, contributing to an overall volume of 1.3 billion m^3/year.

Water harvesting has great potential to increase water efficiency for human consumption, and for agricultural uses. FAO, in partnership with the Ministry of Agriculture and Land Reclamation of Egypt, the European Union, and the Italian Cooperation, recently implemented "Water Harvesting and Good Agriculture Practices for Improved Livelihood, Increased and Sustained Production in Matrouh Rain-fed Agricultural Areas" (FAO, 2021a). The project constructed 323 water harvesting cisterns and rehabilitated 18 cisterns from the ancient Roman period to create a total water capacity of around 9 000 m^3.

1.4 Methodology used in this report

This study is part of a wider project to identify sustainable agriculture practices in Egypt and aims to support sustainable increased agricultural production while addressing climate change and environmental degradation.

The methodology identified the interlinkages between the selected agricultural practices and the three pillars of CSA, based on evidence from the literature reviews and information from field visits. This analysis examined the impacts of the sustainable practices and productivity, adaptation and mitigation, and synergies and trade-offs between the practices and each pillar of CSA.

A team of specialists conducted a desk review of existing sustainable agriculture practices, field visits, meetings, and interviews with relevant stakeholders on the extent of sustainable agriculture practices in Egypt.

The team included experts with different technical backgrounds, from the Ministry of Agriculture and Land Reclamation (Desert Research Center and Agriculture Research Center), the Ministry of Irrigation and Water Management, university professors, experts from the Centre for Environment and Development for the Arab Region and Europe (CEDARE), and staff from FAO Regional Office for the Near East and North Africa and FAO Egypt.

Data were collected through consultation with a range of stakeholders including farmers (men and women), heads of villages, youth and women's groups, extension staff, researchers, university professors, experts, governmental officials, and investors. Discussions with the different groups were held to collect information on the agricultural practices at the farm level and their adaptation and/or mitigation values in addressing specific impacts of climate change, as well as their benefit in increasing resilience of the local farmers.

The major issues include:

- challenges facing agricultural productivity in the specific location;
- perceptions of climate change and observed impact on agricultural productivity;
- specific actions and measures (innovative and/or traditional) used to address climate change impacts;
- understanding of the concept of sustainability and its relation to productivity and profitability;
- practices for efficient use of water resources, fewer agrochemicals, use of biofertilizers and integrated pest management (IPM) practices, use of new varieties adapted to drought, heat and salinity, and agricultural waste management.

The qualitative and quantitative data and information collected from each location were analysed and discussed in the context of the literature reviews. Team members studied the major trends and conditions of the agricultural practices in general and in each of their visited locations.

This study assesses each of the agricultural practices observed in the field. Practices identified as indigenous knowledge, either newly introduced or disseminated, were considered CSA if they addressed at least two of the three CSA pillars.

CHAPTER 2:
Impact of climate change on the agriculture and water sectors in Egypt

2.1 Agriculture in Egypt: challenges and opportunities

The agricultural sector contributes 14 percent to Egypt's gross domestic product (GDP), provides up to 28 percent of job opportunities (FAOSTAT, 2019). It supports the current population of 102.3 million people (World Bank, 2020) which is expected to increase to 160 million people by 2050 (FAOSTAT, 2019). Agriculture remains a source of livelihood for more than 57 percent of the population, employing almost 30 percent, or 6.5 million people, of the workforce. Agriculture work composes 55 percent of employment in Upper Egypt, as indicated by Statista (2020). Furthermore, agriculture is the leading sector of employment for women, employing over 45 percent of Egypt's female workforce (USAID, 2021).

Egypt's agricultural land can be classified into two main categories: "New Lands", or land that has "been reclaimed [from the desert] relatively recently," and "Old Lands", of the Nile Valley and the Nile Delta, which have been irrigated and intensively cultivated since early civilizations (World Bank, 2020). FAOSTAT (2019) showed that in 2019, the top five commodities produced by Egypt were maize (2.39), paddy rice (1.92), potatoes (0.42), sugar beet (0.50) and wheat (3.38) (in millions of feddan). Cropping patterns do not differ greatly across Egypt. The most common crops that small farmers cultivate are clover, corn, rice, vegetables (namely potatoes and tomatoes) and wheat, with cotton, fruit and sugar cane being less commonly cultivated (Keo *et al.*, 2019). Egypt's agriculture is dominated by small farms that rely on traditional cultivation practices (USAID, 2021).

Rainfed agriculture in Egypt is located in the north close to the Mediterranean coast, where precipitation ranges from 130 to 150 mm in the northwestern coast and from 80 mm (west of Al-Arish) to 280 mm (at Rafah) in the northeast. In these regions, barley, wheat, olive, and fruit trees are the main agricultural production, as they use the seasonal rainfall and groundwater resources. However, reliance on seasonal rain is threatened by precipitation uncertainty, drought, and floods induced by climate change. Rainfall fluctuations pose a large threat to Egypt's rainfed agricultural system (Ouda *et al.*, 2016).

Water is the limiting factor of agricultural production in Egypt. The Nile River is the main source of water, providing a fixed amount of 55.5 billion m^3 in water and comprising 97.7 percent of Egypt's resources. The rest of Egypt's water is sourced from groundwater (1.56 billion m^3), rainfall harvested (1.05 billion m^3), desalination (0.10 billion m^3), reused treated wastewater (2.9 billion m^3), reuse of agricultural drainage (9.7 billion m^3) (Abd Ellah, 2020).

Due to climate change, water scarcity is increasing, posing challenges for the agriculture sector, which has the highest demand for water. With increasing water scarcity, agriculture can resort to the reuse of drainage water, however, that too is compromised by climate change.

Salinity is another important water quality issue. Drainage return flows to the Nile result in an increase in salinity of the water from 250 ppm at Aswan to 2 700 ppm at the Delta barrages (EEAA, 2016) and to 39 000 ppm at the Damietta Branch (Abdel Galil, 2020).

In addition to water challenges, Egypt also faces land limitations. **Table 1** illustrates the major indicators of the agricultural sector in Egypt between 1970 and 2018. Although there is an increase in the percentage of agriculture land from 2.9 to 3.85 percent of the total area, there is a significant decrease in arable land from 0.1 to 0.03 hectares per person due to an almost threefold population increase (World Bank, 2020).

TABLE 1. Changes in the agricultural sector indicators in Egypt from 1970 to 2018

Indicator	1970	1980	1990	2000	2010	2018
Total population, million	34.5	43.3	56.1	68.8	82.8	98.4
Agriculture land ((% land area)	2.9	2.46	2.66	3.31	3.69	3.85
Permanent cropland (% of land area)	0.1	0.16	0.37	0.49	0.80	0.93
Arable land (% of land area)	2.7	2.30	2.29	2.81	2.89	2.92
Arable land (hectares per person)	0.1	0.05	0.04	0.04	0.03	0.03
Value added ((% GDP)	24.1	16.58	18.51	15.54	13.34	11.23
Employment in agriculture (% male employment)	NA	NA	NA	27.43	24.72	21.66
Employment in agriculture (% female employment	NA	NA	NA	39.41	42.87	21.69

Source: **World Bank.** 2022. World Development Indicators. In The World Bank Data Catalog. Washington DC. [Cited 23 September 2022] http://data.worldbank.org/data-catalog/world-development-indicators

From a socioeconomic perspective, women are disadvantaged in the Egyptian agricultural system, as crop cultivation varies according to gender. Male farmers cultivate strategic crops such as cotton, maize, rice and wheat, and the bulk of extension services are provided for these crops. Women cultivate vegetables and fruit crops, which are considered less strategic and therefore receive limited extension services (FAO, 2021b). According to FAO (2021b), because women have limited access to information, services, and finance, women-headed households tend to choose to cultivate low-value crops.

2.2 Vulnerability of the agrifood system in Egypt to climate change

Vulnerability has been defined as "the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2022). Vulnerability differs within communities and across societies, regions, and countries, and also changes over time.

Vulnerability is higher in locations with high levels of poverty, governance challenges, limited access to basic services and resources, violent conflict, and high levels of climate-sensitive livelihoods (for example, smallholder farmers, pastoralists, fishing communities) (high confidence). In line with this definition, this report outlines the vulnerability of Egypt's agricultural system to climate change effects.

Egypt is one of the lowest contributors to global carbon dioxide (CO_2) emissions, with only 0.63 percent emissions per capita. In fact, Egypt showed a decrease from 2.59 per capita metric tonnes of CO_2 in 2017 to 2.46 per capita metric tonnes of CO_2 in 2019, a nearly five percent drop. Despite its low contribution, Egypt is greatly impacted by climate change. The country has been ranked as the

83rd most vulnerable country and the 129th most-ready country in the world, with a rank of 107 on the Notre Dame Global Adaptation Initiative (ND-GAIN) country index (University of Notre Dame, 2022).

The vulnerability of the agrifood system in Egypt to climate change is due to its dependence on climate-sensitive sectors. In a country like Egypt, which does not produce sufficient food for its current population, the additional challenge of climate change will have a direct adverse impact on the livelihood of millions of people and lead to hardship throughout the entire economy.

The projected increase in temperature from 1.6 °C to 2 °C for the Nile Valley and Delta (ESCWA*et al.*, 2017) is expected to widen the gap between water resources and demands, decrease the overall agriculture productivity, and increase competition for natural resources. The higher temperatures will increase water evaporation and water consumption and put a further strain on the acute water scarcity in the country.

Climate variability will also impact crop vulnerability to changes in pest infestation and plant diseases. The fall armyworm is one example of those insects that have recently become more dangerous due to increases in temperature. It represents a serious threat to Egypt's food security, as it attacks many basic food crops.

The expected rise in temperature will also lead to a decreased harvest of some major crops such as maize, rice and wheat. Temperature rise will also reduce the production of livestock and affect the productive potential of many agricultural zones in the country and will increase desertification (Lewis *et al.*, 2018).

Egypt is also threatened by sea level rise. In 2020, the World Meteorological Organization (WMO) reported that the global mean sea level has risen since the early 1990s by an average rate of 3.2 +/- 0.3 mm/year. However, the rate of rise is trending higher (4.0-5.0 mm/year) in the northeastern Africa region (Egypt and the Nile Delta) (WMO, 2020).

Seawater intrusion is projected to increase both water and soil salinity of the Northern Delta, which will have major impacts on the livelihoods of millions of farmers. Dasgupta *et al.* (2007) reported that Egypt has the highest percentage of the population exposed to sea level rise, with around 10 percent expected to be impacted by a 1m rise. Studies on the vulnerability of the city of Alexandria showed that even a sea level rise of 0.3m would lead to infrastructure damage worth billions of dollars. Sea level rise is already leading to poor water quality in coastal freshwater lagoons and adversely impacting fisheries and biodiversity. Figure 4 shows the potential impacts of sea level rise scenarios for the North Delta of Egypt.

Studies indicate that major crop yields will be considerably reduced, with some studies predicting 15 and 19 percent reductions in the productivity of two major crops in Egypt (maize and wheat) by 2050 (Abou Hadied, 2006). The impact will be somewhat less on the irrigated wheat than on rainfed wheat elsewhere in the region (Lewis *et al.*, 2018). Losses in crop productivity are mainly attributed to the projected temperature increase, crop-water stress, new pests, and disease, sea water inundation and soil salinization.

Ahmed *et al.* (2021) assessed the economic impact of climate change on agriculture in Egypt using the multimarket model. The results indicated that at the worst-case scenario, with lower yields and higher water demand, the decrease in agricultural production is estimated at a range of 10 to 18 percent loss for major products, with an expected increase in unemployment in the agricultural sector. It has been expected that consumer prices will be raised by seven to 24 percent for all commodities.

FIGURE 4. Sea level rise scenarios for the Nile Delta in Egypt

Source: **GRIDA.** 2015. Potential impact of sea level rise: Nile Delta. In GRID ARENDAL, a UNEP Partner. https://www.grida.no/resources/6479

2.3 Climate change in Egyptian policies

The 2030 Sustainable Development Strategy (SDS) recognizes climate change as one of the main challenges facing development in Egypt, representing an obvious risk to both water and land resources. This affects the coastal areas that are vulnerable to sea-level rise and the related economic and social damages to the urban and rural areas of the northern coastal areas. The SDS calls for efficient and sustainable use of water resources at all levels, especially in the face of population increase and the intensification of climate change. It also calls for the sustainable management of waste as a mitigation measure for reducing GHG emissions.

The National Council on Climate Change was established by the Prime Minister's decision no. 1129 of 2019 as the national authority concerned with climate change-related issues and to ensure mainstreaming climate change effects into the decision-making processes.

The Council has the following major tasks:

- Design the general policies of climate change for Egypt as well as develop and update the national and sectoral strategies and plans to address climate change.
- Link national policies, strategies, and plans for climate change with the sustainable development strategy.
- Follow-up on the negotiations processes within United Nations Framework Convention on Climate Change (UNFCCC) and the resulting protocols or agreements.
- Incorporate climate change concerns into the national sustainable development strategy sectoral plans and provide the necessary financial support for implementing these plans.
- Raise awareness of officials, decision-makers and the public about climate change.
- Integrate concepts and knowledge related to climate change within the education system.
- Build the institutional and individual capacities needed to deal with climate change challenges.
- Reinforce the adoption of the protocol on integrated coastal zone management (ICZM) in Egypt to prevent coastal erosion.

Integrating climate change-related concerns into the agrifood and water sectors were recognized at the strategic level in: 1) the National Environmental Action Plan of Egypt 2002-2017; 2) the several versions of Egypt's National Communication on Climate Change; 3) the updated nationally determined contributions (NDC); and 4) Egypt's National Strategy for Adaptation to Climate Change and Disaster Risk Reduction.

Egypt's NDCs provide adaptation measures in agricultural ecosystems, including changing cultivars to those that are more tolerant to heat and salinity, and pests as adaptation measures for crops. It also promotes water use efficiency, wastewater reuse, desalinization, water quality and pollution management, rainwater harvesting, and water-related ecosystem protection and restoration measures (Crumpler *et al.* 2022).

The NDCs also promote policy settings to build an effective institutional system to manage climate-change associated crises and disasters at the national level. In 2022, Egypt launched the National Climate Change Strategy 2050, formulated its National Adaptation Plan (NAP), updated its NDCs, and finalized its Fourth National Communication to the UNFCCC. The updated 2022 NDC confirmed that the country remains particularly vulnerable to the impacts of climate variability and change, particularly with respect to water security, agriculture, and livestock. It indicated increased risk of adverse conditions for health and human settlements, and energy demand and supply.

Development partners are contributing to Egypt's efforts to address climate change challenges through a number of projects, including:

Sustainable Agriculture Investments and Livelihoods Project (SAIL) (2014-2023) (total International Fund for Agricultural Development [IFAD]/GEF: USD 94.6 million - GEF/Special Climate Change Fund grand: USD 7.8 million). This project is designed to enable vulnerable smallholder farmers to increase their incomes and increase the efficiency of their irrigation systems and diversify their livelihoods to adapt to climate change in newly reclaimed lands in five governorates. The project is funded by the GEF and IFAD and is implemented by the Ministry of Agriculture and Land Reclamation.

Building Resilient Food Security Systems to Benefit the Southern Egypt Region (2013-2018) (Adaptation Fund/World Food Programme [WFP]: USD 7 million). This project introduced adaptation measures such as irrigation improvements at the farm level and agroforestry techniques to improve the adaptive capacity of communities in the southern part of the country. The project built institutional capacity at the national, regional, and local levels to enable sustainability and replication of project activities, and to allow decision-makers to better understand climate trends and impacts. The project was funded by the Adaptation Fund and implemented by WFP with the Ministries of Agriculture and Land Reclamation and Environment.

Participatory Development Programme in Urban Areas (PDP) (2012-2018) (German Agency for International Cooperation [GIZ]: USD 4 million). The project was implemented in cooperation with the Ministry of Housing, Utilities and Urban Communities and the Ministry of Environment. The programme is preparing a local Adaptation Strategy for Giza Governorate and implementing small-scale adaptation measures in informal areas.

Adaptation to Climate Change in the Nile Delta through Integrated Coastal Zone Management (2009-2017) (GEF/ United Nations Development Programme [UNDP]: USD 4.1 million). The project was funded by the GEF/UNDP and implemented through the Ministry of Water Resources and Irrigation. The project integrated the management of sea-level rise risks into the development framework of Egypt's Low Elevation Coastal Zone in the Nile delta region. The project has demonstrated several low-cost, environment-friendly coastal protection systems.

Enhancing Climate Change Adaptation in North Coast and Nile Delta Regions in Egypt (2018-2024) (Green Climate Fund [GCF]/UNDP USD 31.4 million). The GCF/UNDP project is implemented with the Ministry of Water Resources and Irrigation which provides a co-funding of USD 8 million for the construction of 64 km of sea defense systems along the Nile Delta Coast. The project upscales the coastal protection systems that were demonstrated in the GEF/UNDP project. The project will also support the development of a Climate Resilient ICZM plan. Shore Protection Authority is committed to mainstreaming its budget to support the implementation of the ICZM plan.

Sustainable Agriculture Investments and Livelihoods Project (Ministry of Agriculture and Land Reclamation and GEF-IFAD: USD 94 666 500). The Ministry of Agriculture and Land Reclamation (MoALR), in partnership with IFAD/SAIL project, established an early warning system that helps build a database of climate information. Five meteorological stations that are managed and maintained by the Agriculture Research Centre. The forecasted data is analysed by the experts in ARC, and are sent to farmers with extension information specific to their target areas. The text messages contain guidance regarding irrigation, use of fertilizers, and use of pesticides with regard to the forecasted extreme event/weather information. Thereafter these farmers transmit received information through social media and WhatsApp groups across their communities (personal communication with IFAD/SAIL project).

2.4 Transformative changes towards climate-smart agriculture and food systems in Egypt

The challenges facing food security in Egypt call for transformative changes in the agrifood system which will require policies, strategies, and actions to increase the sustainability of the agrifood system. A business-as-usual approach will have severe consequences on the food and nutrition security in the country.

The SDS, known as Egypt Vision 2030, is the long-term strategic plan to achieve the principles and goals of sustainable development in all sectors of Egypt– it aims to create a modern, open, democratic, productive, and happy society. A participatory planning approach was adopted to prepare the SDS: both civil society organizations (CSOs) and the private sector were actively engaged in the process to ensure implementation of the policies, programmes, and initiatives that will be adopted to achieve the SDS targets.

SDS emphasizes increasing self-sufficiency with agricultural products, such as wheat and maize, with sustainable use of the limited water and land resources (FAO, 2017b). The key performance indicators have been identified as:

1. Increase water productivity by 5 percent per year.
2. Double the rate of energy efficiency by 2030.
3. Reduce the intensity of generating municipal waste to 1.5 kg per capita per day.

In the agriculture sector, the SDS emphasizes unlocking Egypt's agricultural sector's high growth potential, generating employment, and productivity gains. It follows a two-pronged approach:

1. Vertical development: increasing production per unit of the Old Lands of the Nile Valley and the Delta by improving water management systems and irrigation networks.
2. Horizontal development: focusing on new reclaimable land in the desert of the Eastern and Western regions, implemented through investment in land preparation and water resources development from aquifers.

The 2030 Sustainable Agriculture Development Strategy (SADS) responds to emerging challenges, including population growth, climate change, and water scarcity by focusing on food security and improved nutrition through sustainable agriculture and employment for women and youth.

The key pillar of the 2030 SADS is the adoption of agriculture as a basis for the economic growth of Egypt. This goal requires increasing agricultural productivity by achieving high and sustainable growth rates, addressing inequalities in rural-urban income distribution, expanding the production of high-value goods, sustainable management of natural resources, and increasing investments in agriculture and non-farming economic activities in rural areas (MALR, 2020).

CHAPTER 3: Selected climate-smart agriculture practices in Egypt

Climate-smart agriculture includes proven techniques, such as more resilient food crops, mulching, intercropping, conservation agriculture, crop rotation, integrated crop-livestock management, agroforestry, improved grazing, and improved water management and innovative supporting practices such as better weather forecasting, and risk insurance (World Bank, 2021).

Practices are considered CSA if they reach at least two of the three pillars. In this report, we have identified the major CSA practices and techniques in Egypt and identified linkages with the CSA pillars (see **Annex 1**).

3.1 Agronomic practices

3.1.1 New varieties tolerant to heat, drought and salinity

With increasing temperatures, especially in southern Egypt, farmers observed many changes in the agronomic behaviour of traditional crops, particularly in the length of the cropping seasons, and in yields and harvesting times for wheat. In El Kharga Oasis, farmers adopted new heat- and drought-tolerant wheat varieties, such as Giza 168. The Agricultural Research Center in Egypt has a long-term breeding programme to develop such varieties. Abdelmageed *et al.* (2019) describe the breeding of durum wheat by farmers in different areas in Egypt to increase tolerance to heat, salinity, and drought stresses (**Table 2**).

Rice cultivation has been considered one major GHG emitter agricultural activity (IPCC, 2007). In Egypt, rice is an important crop with total cultivated area of approximately 452 thousand ha (FAO 2016). Farag *et al* (2013) estimated emissions of methane from rice cultivation in Egypt to be 0.385-ton CH_4 /ha/year that equivalent to 8.106-ton CO_2/ha/year.

Because of the longer growth duration of the late maturing variety, its CH_4 emission was significantly higher than that of early maturing variety (Win *et al* 2021). In Egypt, using early maturity rice variety (125days) such as Giza 177 and Sakha 106 will contribute less methane emission compared to the late variety (more than 145 days) such as Sakha 101 and Giza 176 (Abdelmageed *et al.*, 2019).

For the North Delta, rice varieties have been developed and used for more efficient use of water and higher water productivity. Mehana *et al.* (2021) compared different rice varieties in terms of their water productivity and recommended their use for the cropping system in the Delta (**Table 3**). Choosing such resilient varieties is an important CSA tool. Crops that are well-adapted to the prevalent impacts of climate change are essential to maintaining steady production and profits: resilient crops mean resilient food systems, allowing farmers to harvest nourishing produce and establish a sense of food security (FAO, 2011).

TABLE 2. Bread and durum wheat varieties currently grown in Egypt

No.	Variety	Region	Characteristic
Bread wheat			
1.	Giza 168	All governorates	Tolerates water deficit, heat tolerant, resistant to rusts, late maturing (165-170 d), medium plant height, white grain colour, thin spikes.
2.	Gemmeiza 7	South & Middle Delta	Resistant to rusts, moderate salinity tolerance.
3.	Gemmeiza 9	North Egypt, Giza, Fayum, Nubaria	Sensitive to salinity and water deficit, tall plant height, long spikes, late maturing (160 d), resistant to rusts.
4.	Gemmeiza 10	North Egypt, Giza, Fayum	Resistant to rusts, medium plant height, medium spike length, matures at 154 d, produces a large number of tillers.
5.	Gemmeiza 11	North governorates	Resistant to rusts, early maturing (150 d).
6.	Gemmeiza 12	North Egypt and Toshka-Ewinat	Newly released, resistant to rusts, heat tolerant, medium plant height, long spikes, matures at 150 d.
7.	Sakha 93	North governorates	Resistant to rusts, tolerates salinity and heat, short plant height, more tillers.
8.	Sakha 94	All governorates	Resistant to rusts, salinity tolerant, tall plant height, more tillers, medium maturity.
9.	Misr 1	All governorates, New Lands (Toshka-Ewinat)	Resistant to rusts (Ug99) and water deficit, heat tolerant, more tillers, high yield.
10.	Misr 2	All governorates, New Lands (Toshka-Ewinat)	Newly released, resistant to rusts (Ug99), heat tolerant, more tillers, high yield.
11.	Sids 13	All Egypt; newly released variety	Resistant to rusts and water deficit, early maturing (152 d).
12.	Sids 14	All Egypt; newly released variety	Resistant to rusts and water deficit, early maturing (152 d).
13.	Shandaweel 1	All governorates	Newly released, resistant to rusts, more tillers, long spikes and big size, early maturing (152 d).
14.	Giza 171	All governorates	Newly released, resistant to rusts diseases, medium plant height, long spikes, early maturing (150 d).
15.	Sakha 95	All governorates	Newly released, resistant to rusts and high protein content (13.5%).
Durum wheat			
1.	Sohag 4	Middle Egypt, Toshka, Ewinat	Resistant to yellow rust, more tillers, high protein content (13%), high yield, heat tolerant.
2.	Benisuif 1	Middle and Upper Egypt, Toshka and Ewinat	Resistant to yellow rust, high yield, heat tolerant.
3.	Benisuif 4	Middle Egypt Benisuif and Elmenia	High-quality grain and good for macaroni, more tillers.
4.	Benisuif 5	Middle and Upper Egypt, Toshka and Ewinat	High yield, good for macaroni, high protein content (13%), heat tolerant.
5.	Benisuif 6	Middle Egypt, Toshka and Ewinat	Newly released, high yield, good for macaroni, high protein content (13.5%), more tillers.
6.	Benisuif 7	Middle Egypt	Newly released, high yield, good for macaroni.

Source: **Abdelmageed, K., Chang Xu-hong, Wang De-mei, Wang Yan-jie, Yang Yu-shuang, Zhao Guang-cai, Tao Zhi-qiang**. 2018. Evolution of varieties and development of production technology in Egypt wheat: A review. *Journal of Integrative Agriculture* 2019, 18 (3): 483-495. https://doi.org/10.1016/S2095-3119(18)62053-2

TABLE 3. Average land productivity, water use efficiency, and water productivity of popular rice cultivars in Egypt

Cultivar	Land productivity		Water Use Efficiency		Water Productivity	
	Tonne/ha	% of the Mean	Tonne/ Thousand m³	% of the Mean	Tonne/ Thousand m³	% of the Mean
Giza 177	9.26	96.66	0.81	103.85	1.24	96.88
Giza 178	9.62	100.42	0.77	98.72	1.30	101.56
Sakha 101	9.79	102.19	0.73	93.59	1.37	107.03
Sakha 102	9.62	100.42	0.84	107.69	1.19	92.97
Sakha 104	9.62	100.42	0.77	98.72	1.30	101.56
Mean	9.58	100.00	0.78	100.00	1.28	100.00

Source: **Mehana, M., M. Abdelrahman, Y. Emadeldin, J. Rohila, and R. Karthikeyan.** 2021. *Impact of Genetic Improvements of Rice on Its Water Use and Effects of Climate Variability in Egypt*. Agriculture 2021, 11, 865. https://doi.org/10.3390/agriculture11090865

TABLE 4. How new varieties tolerant to heat, drought and salinity contributes to the three climate-smart agriculture

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Choosing crop species and varieties that are well adapted to climate change allows keeping constant farm productivity also by reducing loss of products, consequently maintaining steady productions and profits.	Significantly contributes to the adaptation of farming system to prevalent and expected impacts of climate change such as drought, salinity and flooding. Increases the efficiency of use of water and nutrients resources. They contribute to enhancing resilience of the farmers and the food system as a whole.	Rice, wheat and maize varieties that use fertilizers more efficiently will contribute to less GHG emission. Using early maturity rice varieties will significantly reduce methane emission from the rice cultivation.

Source: Authors.

3.1.2 Intercropping

Intercropping is a farming technique where two or more crop species are grown in proximity. It has been widely practised under different cropping systems throughout the world and maximizes the efficient use of land, water, light, and nutrients.

Though different intercropping options are available, all have been shown to improve crop quantity and quality, and diversifying cropping systems, resulting in higher productivity and farmer income.

Egyptian farmers practise intercropping, specifically cereal-legume intercropping, to enhance productivity, reduce soil erosion, fix atmospheric nitrogen, reduce the risk of crop failure, and increase land use efficiency (Awaad and Elnaggar, 2017). It is one of the most common practices that used by farmers in the El Kharga Oasis: they typically plant clover between date palm trees and broad beans with wheat, which allows the legumes to fix nitrogen for use by the cereal crop. In the rainfed area of Matrouh, tomatoes are planted between olive and fig trees. In this case, intercropping provides economic insurance for farmers in case one of the crops fails.

FIGURE 5: Intercropping of date palm trees with Egyptian clover (Berseem) in El Kharga

FIGURE 6: Intercropping of olive tree with tomato in Matrouh

According to Teklewold *et al.* (2019) the practice improves productivity and promotes sustainable utilization of land and water. Intercropping controls weeds, improves water-holding capacity, and has physical, chemical, and biological soil benefits (Finley and Ryan, 2018). It contributes to reduce crop failure risk due to weather shock, increasing food availability and dietary diversity (Teklewold *et al.*, 2019). Intercropping maintains and improves soil carbon stock or organic matter content and reduces the need for chemical fertilizer (Hassen *et al.*, 2017), contributing to mitigating GHGs.

TABLE 5. How new intercropping contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Improves crop quantity and quality. Maximizes the efficiency of use of natural resources, such as land, water, light, and nutrients. Diversify cropping systems, therefore contributing to reduce the risk of crop failure due to weather shock. As a consequence, it increases food and feed availability, dietary diversity, farmers' income and human wellbeing.	Provides economic insurance for farmers in case one of the two crop fails. Increases land use efficiency Reduces use of chemical fertilizer due to fixing atmospheric nitrogen as in the case of legume and cereal intercropping Controls weeds. Reduces soil erosion Improves soil structure, therefore increasing water holding capacity. Improves soil biodiversity therefore contributing to enhanced physical, chemical and biological characteristics of the soil.	Maintains or improves soil carbon stock or organic matter content. Reduces the need for chemical fertilizer, therefore reducing GHG emissions derived from their production processes.

Source: Authors.

3.1.3 Bio-Fertilization: Application of symbiotic *Rhizobium* bacteria

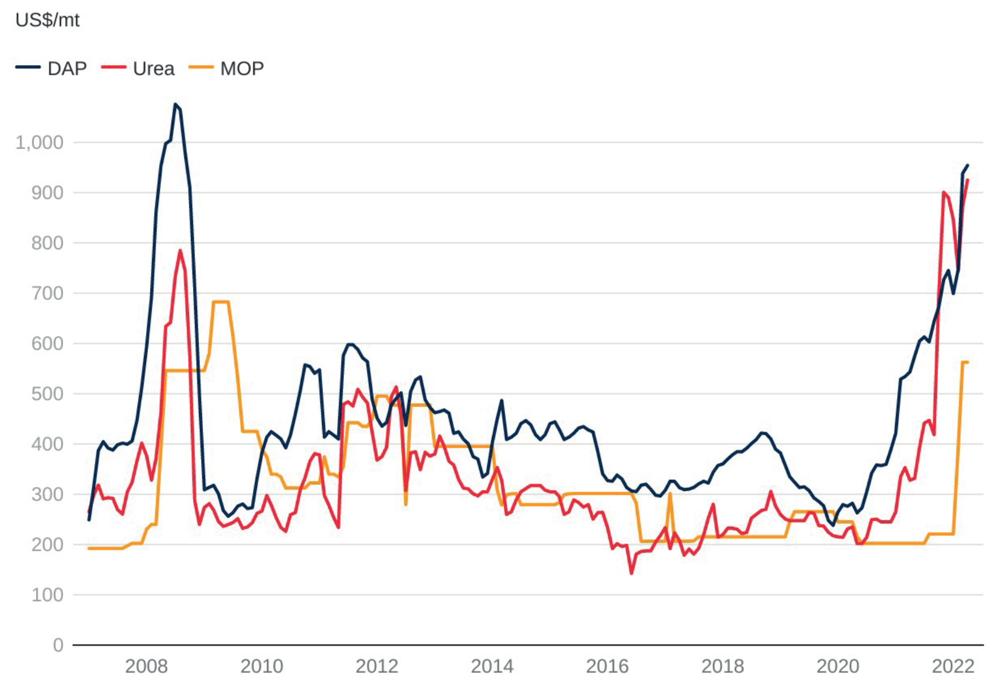
Egypt is the largest nitrogen fertilizer consumer in Africa, but with low nitrogen use efficiency. Using bio-fertilizer provides an opportunity to reduce the amount of applied chemical fertilizers, enhance and maintain soil fertility and quality, which all contribute to increasing productivity and farmer profit. Soil is also less susceptible to the externalities of climate change, increasing resilience of the agrifood system.

A good example of biofertilizers is the commercial product Okadine. Okadine contains symbiotic *Rhizobium* bacteria, which have the capability to fix atmospheric nitrogen and provide it to plants as an important plant nutrient. Applying Okadine to legume crops saves a considerable amount of chemical low-efficiency nitrogen, which in turn will save farmers money (**Figure 7** shows a recent fourfold increase in fertilizer price).

Further, biofertilizers can mitigate pollution and GHGs as they fix nitrogen in the soil whereas N fertilizer in form of nitrate leaches into and pollutes the groundwater.

It was observed during the field visits that using Okadine as an organic supplement is normal practice for many small-scale growers. The economic and environmental value of using Okadine was well discussed and investigated in one of the farmer field schools. Farmers said that using Okadine saves 50 percent of the nitrogen fertilizer needed for crops.

FIGURE 7. Increase in fertilizer prices from April 2008 to April 2022

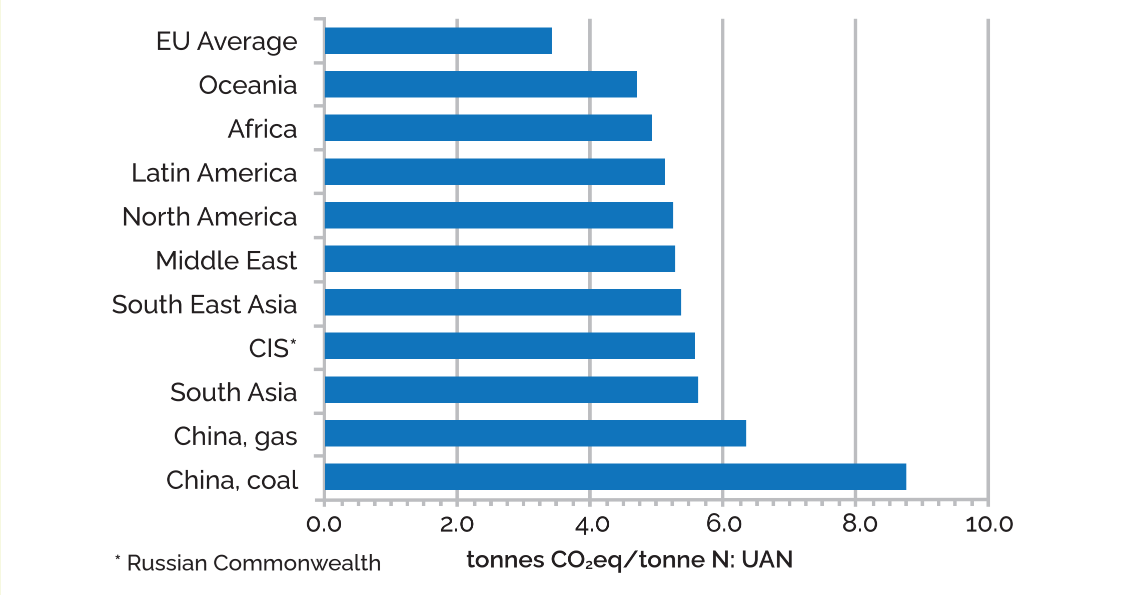


Note: DAP = diammonium phosphate. MOP = muriate of potash. Last observation is April 2022.

Source: **World Bank Blogs.** 2022. Fertilizer prices expected to remain higher for longer. Baffes, J. & Chian Koh, W. *Published on Data Blog*. Cited May 11, 2022. https://blogs.worldbank.org/opendata/fertilizer-prices-expected-remain-higher-longer

Applying biofertilizers such as Okadine rather than nitrogen chemical fertilizer contributes to the climate change mitigation process by decreasing CO_2 emissions, whereas production and use of mineral fertilizers consumes energy and emits CO_2 and other GHG. **Figure 8** shows the carbon footprint of the chemical fertilizer (urea) produced in different regions of the world (International Fertilizer Society, 2019).

FIGURE 8. Carbon footprint of urea produced across regions



Source: **Hoxha, A. & Christensen, B.** 2019. The carbon footprint of fertiliser production: regional reference values. *Paper presented to the International Fertiliser Society in Prague*, 8 May 2018. International Fertiliser Society. https://www.fertilizerseurope.com/wp-content/uploads/2020/01/The-carbon-footprint-of-fertilizer-production_Regional-reference-values.pdfi

FIGURE 9. Application of biofertilizer (*Rhizobium*-Okadine) for faba beans field in El Kharga

FIGURE 10. Planning for farmer field school on biofertilizer use in El Kharga

TABLE 6. How applying biofertilizers contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Using "Okadine" as biofertilizer saves 50% of the N fertilizer applied to crops, therefore reducing costs and increasing farmer income.	Contributes to enhancing and maintaining soil-fertility and quality. This, in the long term, prevent soil depletion, increase resilience and ensure productivity and farmer profit. Reduces soil and water pollution due to losses of chemical N fertilizers in form of leached nitrates.	Reducing use of chemical N fertilizers caused less consumes of energy and emissions of CO_2 and other GHGs due to N fertilizers production.

Source: Authors.

3.1.4 Mulching

Mulching is a valuable agricultural practice that contributes to soil and water conservation and is used by farmers in several of the study sites. Mulching uses organic (for example, crop residues, straw, grasses, and farmyard manure) and/or inorganic and synthetic materials, (for example, polyethylene sheets, and gravel).

Farmers confirmed mulching's capacity to reduce soil erosion, retain soil moisture, increase water-use efficiency, modify soil temperature, and, in the case of organic mulching, release nutrients to the soil through the natural decay of organic matter. Mulching is a sustainable solution to commonly-reported effects of soil nutrient decline due to climate change, thus helping to adapt to climate change impacts. Using mulching materials led to a significant decrease in accumulation of salts in the root zone under different irrigation treatments.

In their study in Egypt, Abd El-Mageed *et al.* (2016) reported that organic and inorganic soil mulching could be considered a potential field application in squash production for increasing yield. Such methods were used in Armant Village, Luxor, where several farmers practised mulching using plastic sheets around each seedling. FAO (2020) reported that soil mulching results not only in the conservation of soil moisture but also contributes to suppressing the growth of weeds.

FIGURE 11. Mulching with plastic sheets in Luxor

TABLE 7. How practicing mulching contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Allows soil to retain its moisture by shading the ground and reducing soil evaporation, therefore resulting in higher water use efficiency. Protects soil from increasing soil temperature. It is a natural solution for the increasing heat that is damaging plant productivity. Replenish soil nutrients through natural decay in case of organic mulch. Suppress weeds' germination and growth. For all the above-mentioned reasons it increases agricultural yields sustainably. It is also a low-cost method, which combined with increased yields will enhance farmer profit. .	Reduces soil erosion, by protecting soil from rainfall and wind. Provides shelter from two unpredictable and threatening elements critical to agriculture- heat and water. Promotes food system resilience by increasing water use efficiency due to the slowing of natural evaporation. It works as a natural fertilizer through the natural decay when organic matter is used. This not only allows for better yield resilience but can also allow for higher nutrients uptake by plants leading to benefits for people's health. Led to a significant decrease in accumulation of salts in the root zone under different irrigation treatments, therefore protecting soil quality.	Wood mulch has been found to cut NO_2 emissions by up to 23% (Mesfin *et al.*, 2016) NO_2 is a GHG 300 times more potent than CO_2. Organic mulch works as an additional source of carbon for soil.

Source: Authors.

3.1.5 Cultivation on wide ridges

In several locations, cultivating wheat on wide ridges was identified as a widely adopted CSA practice. Wde ridges cultivation reduces growth of the harmful weeds, saves irrigation water, and decreases the amount of applied chemical fertilizers and pesticides. This allows for a significantly higher yield and better adaptation to climate change.

In sugar cane cultivation in Luxor, farmers consider terracing more efficient than row planting. Sugar cane growers indicated that terraces could save up to 40 percent of the water requirements needed when compared with conventional farming in rows.

The benefits of this farming system are increased sustainable productivity and better climate-change adaptation. Farms with wide ridges store a third more soil organic matter (SOM) than farms under conventional agricultural practices (Saiz *et al.*, 2016); organic matter plays a crucial role in determining soil quality, and its enhancement may generate production, adaptation, and mitigation benefits through the regulation of carbon, oxygen, and plant nutrient cycling. Prime organic soil matter promotes carbon sequestration, also mitigating the contribution of agriculture to climate change.

FIGURE 12. Cultivating wheat on wide ridges

TABLE 8. How cultivation on wide ridges contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Increase the efficiency of natural resources use, such as soil, water and nutrients, therefore resulting in higher yield. Reduce loss of products and the consequent reduction of income. Improve crop quantity and quality.	Reduce growth of harmful weeds, save irrigation water, decrease amount of chemical fertilizers and pesticides required, ultimately saving soil quality. Reduce water requirements compared with conventional farming on rows.	Protect and conserve existing soil organic matter Contributing to the carbon sequestration in the soil. Store more SOM than farms under conventional agricultural practices.

Source: Authors.

3.1.6 Sugar cane budchips for seedlings production

In Most of Egypt's sugar cane cultivation is located in Upper Egypt (Minya, Sohag, Qena, Aswan, and Luxor Governorates) and the local economy is heavily dependent on refined sugar cane sugar, with more than five million people are dependent on sugar cane growing and sugar production for their livelihoods.

Sugar cane has a very high-water requirement that has been calculated between 11 500 and 14 995 m^3 per feddan/season, depending on the location, with requirements expected to increase due to climate change (Abdrabbo *et al.*, 2021).

New techniques for planting sugar cane in Egypt have been introduced to reduce the quantity of seeds needed and improve the quality of the sugar cane produced. Instead of the usual wasteful practice of using stalk cuttings, excised axillary buds of the sugar cane stalk, known as bud chips are planted, saving 96 percent of the sugar cane previously used as seeds by weight (Galal, 2016). This reduces the cost of cultivation and saves millions of tonnes of raw material that can be used for extracting sugar rather than being buried in the soil as seed.

FIGURE 13. Sugar cane budchips for seedlings production in Luxor

The Ministry of Agriculture and Land Reclamation (MALR, 2020) infographic indicates that cultivation using the seedling system results in increasing the average productivity of each feddan from 33 to 55 tonnes, reducing planting costs, increasing fertilizer use efficiency by up to 30 percent, and reducing water use by 35 percent.

TABLE 9. How using budchips for sugar cane cultivation contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove greenhouse gas emissions where possible
Saves about 96% of the sugar cane previously used as seeds by weight. Reduces cost of cultivation. Saves tonnes of raw material that can be used for extracting sugar rather than been buried in the soil as seed. Increases the average land productivity, from 33 to 55 tonnes per each feddan. Saves both resources and money, farmers have better use of time and land area: such benefits increase productivity, and farmer income.	Increases fertilizer use efficiency, therefore reducing the need of chemical fertilizer by 35%. Allows saving about 30% of the irrigation water.	Reduces GHG emissions required for fertilizers production.

Source: Authors.

3.1.7 Protected agriculture

Protected agriculture is the process of growing crops in optimal growing conditions often using technology to achieve ideal temperature, moisture, lighting, pest management, and plant nutrition. Protected agriculture is practised in several locations in Egypt and under different farming systems, such as Matrouh and Qalyoubia, where vegetables, date palm seedlings, and mulberry trees are planted before being transferred into the field.

38 600 feddan of land are used for protected agriculture in Egypt, producing mainly peppers, tomatoes, cucumbers, cantaloupes, beans, strawberries and melons. Protected crops are now grown in more than 61 817 polyethylene greenhouses (including high tunnels) with an average size of 570 m^2.

Egypt has approximately 9 700 feddan of glass greenhouses. Since February 2018, Egypt has launched thousands of greenhouses as part of the country's greenhouse mega project, which is expected to produce over 1.5 million tonnes of vegetables per year and provide more than 300 000 direct job opportunities (Xinhua, 2020). A national project will establish a further 10 000 greenhouses on an area of 4,200 thousand feddan in the Governorates of Beni Suef, Fayoum, Ismailia, Minya, Matrouh and Sharqiya.

Protected agriculture reduces water consumption of plants grown in the greenhouse by more than 50 percent compared to open field production, and increases yields up to three times compared to open-field agriculture (FAO, 2021c). It is an efficient option to address the water scarcity challenge in Egypt, providing a form of climate resilience.

FIGURE 14. Protected agriculture in El Kharga and Qalyobia

Protected agriculture systems also provide effective protection against weather and environmental conditions; support higher yields and improve water use efficiency maximizing the use of each unit of land.

Greenhouse production uses large amounts of energy for heating and refrigeration during seasonal shifts, artificial lighting, (Antón *et al.*, 2012), post-harvest transport, packaging (Theurl *et al.*, 2017), and the use of fertilizer and growing media. This leads to high amounts of GHG emissions and poses a trade-off for climate change mitigation. However, protected cultivation includes a multitude of mediums, such as glasshouses, plastic houses, tunnels, or screen houses, and a multitude of aspects such as energy use for heating, fertilizer and pesticide use, and choice of plant substrates. Different structural choices could widely decrease emissions, such as maximum insulation, smart climate control, and sustainable energy sources such as biogas, photovoltaics and geothermal energy (Grudaa, 2019). With such adaptations, trade-offs of protected agriculture on climate change can be mitigated.

TABLE 10. How protected agriculture contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Increasing farm profitability, by allowing for the cultivation of high value crops (for example, horticultural crops, and fruits) possible thanks to effective protection against extreme weather events (for example, hail) and environmental conditions. Reduces water consumption by more than 50% compared to open field production and increases yields between two and three times compared to open-field agriculture (FAO, 2021c).	Improves input use efficiency (for example, water, land, nutrients) and allows for the diversification of farm produce, ultimately contributing to increasing resilience and adaptive capacity of the local communities.	Trade-offs: high cost for initial investment, which vary depending on the type and size of protective measure adopted. Greenhouse systems can require large amount of energy consumption (for example, for heating or refrigeration during the cold or warm season, artificial lighting), and the use of fertilizer and growing media, therefore resulting in higher GHG emissions compared to the BAU. Various measures can be adopted to reduce the impact of higher energy requirements (for example, GHG emissions), such as maximum insulation, smart climate control, use of sustainable energy sources such as biogas, photovoltaics and geothermal energy (Grudaa, 2019).

Source: Authors.

3.1.8 Composting agricultural wastes and residues

It has been estimated that 33.4 million tonnes of agricultural waste are generated annually in Egypt (see **Table 11**). There are also 11 million tonnes of cattle manure and 2.3 million tonnes of animal waste obtained from poultry farms (Abou Hussein and Sawan, 2010). The amount of agro-industrial waste is also considerable with 4.7 million tonnes of bagasse resulting from sugar cane and about 1.6 million tonnes from rice husks (Nakhla *et al.*, 2013). The current methods of dealing with agricultural wastes and residues are ineffective: around 18 percent are used as soil amendments, another 30 percent as animal fodder, and the remainder (52 percent) are not used and burned directly in fields or in low-efficiency burners. Such solutions contribute to the loss of organic matter and to pollution (Elfeki *et al.*, 2017).

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Agricultural waste can be used for compost, animal feed, food, energy, and handcrafts production purposes. Recycling agricultural waste has both environmental and economic benefits and will diversify farmer income and increase agricultural production, leading to improving food security and human wellbeing.

TABLE 11. Amounts of annual agricultural wastes and residues generated in Egypt

Crop residue	Million tonnes
Wheat straw	6.9
Sugar cane residues	6.8
Maize residues	4.5
Rice straw	3.6
Banana residues	1.7
Trees-trimming residues	1.7
Cotton stalks	1.6
Tomato	1.11
Public garden residues	1.14
Sorghum residues	1.2
Vegetable residues	0.71
Date palm residues	0.66
Sesame straw	0.56
Bean straw	0.35
Sugar beet residues	0.32
Potato	0.317
Barley straw	0.2
Pea straw	0.042
Lentil straw	0.012
Total	33.421

Source: **Abou Hussein, S. and Sawan, O.** 2010. The Utilization of Agricultural Waste as One of the Environmental Issues in Egypt (A Case Study). *Journal of Applied Sciences Research* 6(8):1116-1124.

In many parts of Egypt agricultural wastes is burnt, with rice straw in the Nile Delta, sugar cane residues in Upper Egypt, and residues of date palm trees in the Oases. Burning rice straw causes massive damage such as air pollution and CO_2 emissions. Recently, efforts have been made to minimize crop residue burning by converting rice straw to animal fodder, fish feed, organic fertilizers, and as a substitute for wheat straw in poultry farm bedding.

Sugar cane residues can also be used as animal feed. This is not only sustainable but provides a low-price feed compared with feed from wheat straw.

Turning sugar cane residues into compost was a common practice documented by several farmer fields in Luxor in Upper Egypt. Composting date palm tree residues has also been introduced by the farmers in El Kharga Oasis. One farmer initiated his own small business of producing compost and selling it to other farmers in his own and neighboring villages.

This practice helps farmers reduce their use of chemical fertilizers with their adverse impact on groundwater quality due to nitrate leaching, decreased soil biodiversity and emission of GHG. Re-use of waste is a critical CSA solution: it supports the reduction of CO_2 emissions, increases the resilience of crops and sustainability of practices to contribute to better outcomes through using of organic fertilizer sources.

FIGURE 15. Composting agricultural wastes and residues

FIGURE 16. Chopping machines for cutting agricultural residuals in El Kharga

BOX 1. Definition of composting

Chemical fertilizers make nutrients readily available to plants, but their disadvantages outweigh their advantages. Chemical fertilizers contribute directly and indirectly to GHG emissions, environmental pollution and soil loss. Using compost to restore soil fertility contributes to sustainable agricultural practice through recycling farm wastes.

Composting is the natural process of decomposing organic matter by microorganisms under controlled conditions. Composted crop residues, animal waste, food waste, and similar materials can be used as organic fertilizer leading to increased SOM that plays an important role in sustaining soil fertility. In addition to being a source of plant nutrient, it improves the chemicophysical and biological properties of the soil. These advantages manifest themselves in reduced cropping risks, higher yields and lower outlays on inorganic fertilizers.

Source: **FAO.** 2003. *On-Farm Composting Methods, FAO Land and Water Discussion Paper*. Rome.

TABLE 12. How composting agricultural wastes and residues contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Converts organic waste to animal fodder, fish feed, organic fertilizers, and as a substitute for wheat straw in poultry farm bedding. Producing and selling compost can diversify farmer income. Increase agricultural production, therefore improving food security and human wellbeing.	Increase SOM content, therefore improving soil quality, soil nutrients and water holding capacity, therefore increasing soil resilience.	Reduction of burnt directly in fields especially as in the case or rice straw. Reduce the need for chemical fertilizers and increase SOM contributing to carbon sequestration in the soil.

Source: Authors.

3.2 Sustainable water management techniques

3.2.1 Shifting to modern irrigation methodologies

Efficient use of water resources was evident in different locations, and under different soil types, crops, and farming systems, such as in Qaloubia and El Kharga Oasis. Establishing drip irrigation is one of the government's current priorities, with a national plan being developed to introduce drip irrigation throughout the country and help farmers with soft loans so they can install the drip pipes. Drip irrigation has been introduced in one million out of a targeted five million feddan, replacing surface irrigation. Farmers pay the cost over installments with zero interest (Egypt Today, 2021).

When successfully managed, drip and sprinkler irrigation can provide substantial increases in crop and tree productivity for small-scale farmers. In such conditions of water scarcity, it is likely that this practice, compared to other systems, will improve the resilience of farmers through high efficiency and water saving.

Drip irrigation will contribute to increasing the productivity of irrigated cropping systems and increase farmer incomes, while minimizing the risks of social and environmental trade-offs. This practice also contributes to climate adaptation, as it increases the resilience of irrigated cropping systems, protects crop vulnerability from future climate change impacts and other sources of immediate and longer-term risk and uncertainty. It provides a longstanding solution to unpredictable water fluctuations due to climate change.

Drip irrigation also contributes to climate change mitigation, as it can dramatically reduce GHG emissions from soil without sacrificing yields of forage crops. For example, subsurface drip irrigation is a promising management solution that can limit emissions via targeted rhizosphere access to water and nitrogenous fertilizers. It improves the environmental sustainability of irrigated cropping systems and value chains while safeguarding the basic human water requirements of rural and urban water users; the livelihoods of women, children and poor or marginal social groups; and the functionality of aquatic ecosystems.

Gated irrigation is another water-saving technique that has been used by farmers. It has been explained by FAO (2002) as a system that controls the amount and direction of irrigation water, as water can be diverted into furrows through gated pipes or hoses connected to a hydrant fitted on buried pipes. In Egypt, Osman (2002) reported that using gated pipes, saved water between 15 to 30 percent is applied to different crops including cotton, wheat, corn, and rice compared with the traditional (flooding) system.

TABLE 13. How shifting to drip and sprinkler irrigation contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	**Adapt and build resilience of people and food system to climate change**	**Reduce and/or remove GHG emissions, where possible**
Increasing farm profitability through the effective use of labour, energy, and water. Efficient water use reduces costs and enhance productivity. Saved money can be used for other purposes.	Improving resilience of farmers by supporting them in facing climate change impacts, such as prolonged drought periods. Reduce nutrients lost, through leaching or runoff, which occurs in case of traditional surface irrigation (channels, flooding)	Drip irrigation can dramatically reduce GHG emissions from soil without sacrificing yields of forage crops.

Source: Authors.

FIGURE 17. Farm converted into drip irrigation in El Kharga

FIGURE 18. Gated irrigation technique

3.2.2 Advanced irrigation solutions

The Ministry of Water Resources and Irrigation has piloted a new methodology for the efficient use of the limited groundwater in the El Khaga Oasis. Sensitive devices to measure the degree of soil moisture are used to monitor pressure from soil moisture deficits and the data is automatically sent to the farmer's mobile phone, helping them to make the appropriate decision regarding the quantity and timing of irrigation and the potential impacts of plant development and soil health, supporting the assessment of drought-tolerant, resilient, and vulnerable crops.

Digital irrigation solutions accomplish all three CSA goals: the project saves water and reduces crop damage while increasing productivity and yield (pillar 1), reduces operating costs and increases farm profitability through the effective use of labour, energy, and water (pillar 2), and rationalizes energy used for pumping water, consequently reducing CO_2 emissions (pillar 3).

FIGURE 19. Sensitive device to measure the soil moisture connected to mobile app

©FAO

TABLE 14. How using advanced irrigation solutions contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Increasing farm profitability through the effective use of labour, energy, and water. Saving water in some areas helps farmers to cultivate more land and increase family income.	Improving the resilience of farmers through high efficiency in the use of water and its saving especially during water scarcity or drought.	Rationalizes energy used for pumping water, consequently reducing CO_2 emissions.

Source: Authors.

BOX 2. Water users' associations and sustainable management of water resources

Water users' associations (WUAs) are organizations created to bring farmers together (usually no more than a few hundred) for the purpose of managing shared water resources. Increased farmer participation in decision making leads to sustainable water use and equitable sharing of the benefits.

Water Users Associations work best when they are created, established and run by their members without external interference.

Functions of WUAs:

- Act as an interface between the farmers and the main system management.
- Fair water distribution.
- Improved operation and maintenance of the irrigation and drainage system.
- Assessment and collection of different charges that the WUAs may decide for maintaining and running the system.
- Dispute resolution amongst members as well as between members and non-members.

Source: **El-Hadad, F., El-Gamal, T. & Mady, A.** 2020. Assessing the role of water users associations in operating and maintaining the improved irrigation system in Egypt. Arab University Journal of Agricultural Science Ain Shams University, Cairo, Egypt, 28 (1): 141-15. 3 https://journals.ekb.eg/article_83187_c2c5724402df3167e1f1e919ca0847f5.pdf

3.2.3 Strengthening water users' association

About twenty farmers in the El Kharga Oasis formed the water users' association (WUA) to help manage their water resources in a sustainable way. The WUA serves to distribute water fairly and according to the agreement between all water users.

In addition to saving and efficiently using limited water resources, the results of Kassem *et al.* (2019) indicated that farmers' ability to adapt to climate change was influenced in part by the membership of WUA. This kind of partnership could improve the exchange of knowledge and collaboration that allow local solutions to combat climate change impacts.

The WUA is a CSA solution as it achieves two pillars: 1) reduces water usage while optimizing resources and increasing yield opportunities; and 2) improves community resilience in the face of changing water supply resulting from climate change.

TABLE 15. How the water users' associations contribute to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Increasing farm profitability through the effective use of labour, energy, and water. Efficient water use reduces costs and enhance productivity. Saved money can be used for other purposes. Using water only when necessary for biological and weather reasons help farmers on increasing productivity.	Improving resilience of communities by supporting them in facing climate change impacts, such as prolonged drought periods.	NA

Source: Authors.

3.2.4 Lining irrigation canals

Lining irrigation canals save water by preventing seepage through canal bores, one of the main reasons for water loss. Egypt has completed lining 2,138 km of irrigation canals in 20 governorates nationwide.

FIGURE 20. Lining main irrigation canals

While lining canals does not necessarily lead to reduction of water losses at the level of the whole Nile Valley (most of the water that is 'lost' returns to the river system and can be used further downstream), lining irrigation canals provides a more reliable water supply for farmers and increased income for families, reduced the costs of maintenance of waterways. Canal lining has also resulted in more equitable distribution and enhanced access to water to the end of the canals.

TABLE 16. Lining Irrigation Canals contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Lining of irrigation canals makes water supply more reliable for farmers and results in an increase of income for families, a reduction of the costs of maintenance and the disinfection of waterways. Equitable distribution and enhancing the access of water to the end of the canals.	Preventing water from seeping into unproductive lands favours a better management of water.	NA

Source: Authors.

3.2.5 Water harvesting

Water harvesting systems have been practiced for thousands of years and are still used by local communities as a vital technique to enhance local resilience. The Bedouin in the northwestern coast of Egypt use water harvesting to maximize the use of limited seasonal rainfall, as well as to protect against unexpected floods. It has been considered an indigenous knowledge practice that has and will become even more essential as the current and expected impact of climate change leads to decreased and uncertain precipitation (ESCWA *et al.*, 2017).

Water harvesting is one of the major practices that has been implemented, in the watershed areas visited in Matrouh, to collect water for agricultural use. Water harvesting also reduces surface runoff and water loss, decreasing soil erosion, and protecting downstream villages from floods. Rehabilitation of some damaged infrastructure, such as the old Roman wells, allow local communities to collect and store rainwater.

FIGURE 21. Constructions for water harvesting in Matrouh

Harvesting water for irrigation strongly contributes to farm profitability by increasing production efficiency and yields per unit of land. It provides yield stability throughout the year by ensuring a constant supply of otherwise unpredictable water. Water harvesting enables crops or fodder to be grown despite inadequate rains or outside growing seasons, contributing significantly to strengthening the resilience of the agrifood system. Water harvesting and improved irrigation also reduce GHG emissions in comparison to other irrigation methods contributing to climate change mitigation.

TABLE 17. How water harvesting contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Water harvesting enables crops or fodder to be grown despite inadequate rains, or outside growing seasons.	Increases farm resilience by increasing water availability and efficiency useful to face a decrease and the uncertainty of precipitation due to climate change. It allows for diversification of cultivated crops. Reduces surface runoff and water loss, therefore, contributing to reduce soil erosion, as well as protecting the downstream villages.	Water harvesting can contribute to lower CO_2 emissions if solar energy is used in pumping the collected water rather than using pumps operated by fossil fuel.

Source: Authors.

3.2.6 Aquafarm (hydroponic) and aquaponics agriculture

Aquafarms are critical for maximizing water efficiency and productivity. At the Ahmed Orabi district, near Cairo, the soil-less agriculture system has been used to grow crops inside greenhouses in water-filled tanks. The system depends upon a set of fans, cooling pads, sprinklers, and greenhouse shading. An integrated automatic system was installed to control temperature, humidity and light to deal with the high temperatures inside the greenhouse.

FIGURE 22. Aquaponics agriculture in Qalyoubia

This method saves about 90 percent of water typically required by traditional soil-grown crops. Aquafarming increases the sustainability and rate of crop production, allowing farmers a steady stream of income despite outside conditions or restraints. Soil-less agriculture not only produces significantly higher yields; it is also important because of its higher water- and fertilizer-use efficiency. It can provide solutions for the arid and saline-prone areas, or wherever the land, water, and climatic conditions are unfavourable (Somerville *et.al*, 2014), increasing the resilience of the local communities. Aquafarming can also reduce GHG emissions typically used by fuel in mechanized agriculture. However, aquafarming can emit GHGs as the systems used to control the temperatures use fuels with high GHG emissions. Despite these emissions, the tradeoff is still exceedingly beneficial (FAO, 2017a).

TABLE 18. How practicing aquafarm and aquaponics agriculture contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Soil-less agriculture allows for the cultivation of high-value crops, in conditions of highly efficient use of input, such as land, water and nutrients. It enhances farmer income thanks to crop diversification, both in terms of type and time of produce availability.	It increases the efficiency of the use of inputs, such as water, land and nutrients, therefore, increasing the resilience of farms and of the entire agrifood system.	Reduces the amount of fertilizers needed by reducing their losses due to leaching or runoff. Reduces GHG emissions due to fuel used for mechanization. Tradeoff for climate change mitigation: the automatic system to control temperature uses fuels, therefore producing GHG emissions.

Source: Authors.

3.3 Renewable energy

3.3.1 Converting livestock waste into biogas

Work is being done to introduce biogas technologies to Egypt, where tons of biomass are available for the production of biogas. By installing biogas units in the households, the animal manure which is currently disposed of in an unsustainable way will be fermented in biogas digesters and a significant amount of methane emission can be eliminated contributing significantly to the decrease of GHG emission in addition to the potential utilization of the digestate as organic fertilizer (El Zayat *et al.*, 2015).

In Luxor organic waste is being used to produce biogas, by using anaerobic digesters in an underground tank where organic wastes decompose in the absence of oxygen. The biogas produced is used for domestic purposes. The by-product of biogas production, "digestate" is collected in another tank to be used as organic soil addition. Biogas production allows diversified farm production and increased access to clean energy, contributing to increased farmer income and as an efficient strategy for agricultural waste and residue disposal.

FAO (2017a) identified the conversion of waste into biogas as one practice that supports all three CSA pillars, by mitigating the GHG emissions derived from the natural decay of agricultural waste (especially animal waste), generating bioenergy, and producing organic fertilizer for small farmers with minimum environmental impact and low GHG emissions.

FIGURE 23. Using biogas for domestic purposes in Luxor

TABLE 19. How converting livestock waste into biogas contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Diversifies farm production, increases access to clean energy source, and serves as an efficient strategy for agricultural waste and residues disposal.	Generates bioenergy and produces organic amendment for small farmers, reducing their dependency on expensive fossil fuels and fertilizers.	Mitigating the GHG emissions derived from the natural decay of agricultural waste (especially animal waste). Replace energy from fossil fuel therefore working as a means for mitigation.

Source: Authors.

3.3.2 Solar pumping irrigation system

Irrigation canals in Egypt are frequently located below ground level, requiring pumps to transfer water to the fields. The pumps are dependent on the use of fossil fuels directly dependent on diesel and indirectly dependent on electricity. Solar pumping irrigation systems (SPIS) provide a low-cost, clean energy source and may reduce the carbon footprint of irrigation systems while also addressing ever-increasing fuel costs.

The Ministry of Water Resources and Irrigation is planning a nationwide programme for the use of solar energy in agriculture. Farmers in El Kharga Oasis have begun to use solar energy for pumping irrigation water allowing them to be less dependent on outside resources, and providing a sustainable and reliable solution, especially in drought-prone areas. In Matrouh a desalinization station uses solar energy to turn salty groundwater into fresh water suitable for drinking and agriculture.

FIGURE 24. Solar pumping irrigation system in El Kharga

By increasing crop productivity and potential profit, SPIS meets CSA pillar 1. Further, it increases the resilience of the farming system to climate change as farmers need not worry about fluctuating fuel availability and affordability or changing water levels due to climate change. Schnetzer and Pluschke (2017) reported that SPIS provide a reliable source of energy in remote areas, contributing to rural electrification and reduced energy costs.

Switching from fuel to renewable energy also contributes to climate change mitigation by lowering GHG emissions. It has been estimated that GHG emissions may decrease 95 percent to 97 percent per unit of energy (CO_2-eq/kWh) for water pumping compared to pumps on grid electricity, and 97 percent to 98 percent compared to diesel-pumps (GIZ, 2016).

TABLE 20. How solar pumping irrigation system contributes to the three climate-smart agriculture pillars

Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food system to climate change	Reduce and/or remove GHG emissions, where possible
Reduces energy costs compared to the use of fossil fuels for pumping irrigation water.	Enhances resilience of farming systems which shall face fluctuation in availability and affordability of fossil fuels.	Reduces GHG emissions compared to the use of fossil fuels to pumping irrigation water.
Provides a reliable and less expensive source of energy for farmers, thus ensuring irrigation systems.	Contributes to enhance the resilience of remote rural areas by providing reliable source of energy.	

Source: Authors.

CHAPTER 4: Scaling up climate-smart agriculture in Egypt: involving all stakeholders

Sustainable rural transformation is paramount in addressing the challenges facing the agrifood system in Egypt. The government is spearheading a number of national initiatives to increase the resilience and adaptive capacity of the agrifood system. This should be complemented by adopting climate-smart agriculture practices at both the farm level by small-scale farmers, and commercial farms and big investors.

Creating an enabling environment is key to upscaling CSA practices and attracting private sectors for more investment in sustainable agrifood transformation. It is fundamental to ensure the involvement of all actors in identifying and implementing CSA activities. Although institutions in the agricultural, water, and environmental sectors are equipped to address major issues, mainstreaming and implementing CSA calls for better coordination between the different relevant authorities and institutions. This requires the cooperation of producers, agro-industrial enterprises, retailers, consumers and public authorities.

4.1 Role of public sector

Several Egyptian Government policies support CSA action: the SDS 2030, the updated Sustainable Agriculture Development Strategy (SADS), and the NDC recognize the adverse impacts of climate change on the agrifood system and identify the major programmes needed to address it. The public sector must be supported to create an enabling environment to allow private sector and civil society stakeholders to make timely and well-informed decisions on sustainable food production, climate change adaptation, and GHG reduction and removal.

All stakeholders need a coherent policy framework that supports the achievement of CSA pillars. Public institutions can support evidence-based CSA solutions by producing and disseminating local, site-specific knowledge and information.

For example, most farmers in rural communities have limited access to relevant weather information and its expected effects on planting dates, water requirements, plant and animal pests and diseases. In this context, it is clear that climate information services (CIS) can provide information to enable farmers to make timely, climate- and weather-informed decisions. CIS can build the resilience of agrifood producers and value chain actors to climate impacts that threaten agrifood systems.

CIS enable agricultural actors to deal with climate and socioeconomic risks, including price fluctuations and climate-driven health crises, enhancing resilience and development through investment in adaptation actions. These clearly meet the pillars of CSA: increase production in a sustainable way, increase adaptation to climate change, and reduce GHG emissions. (FAO, 2022a). However, in order to achieve these goals, countries need to strengthen their capacity to continuously update available information on climate change and identify options to decrease vulnerabilities. Activity that can be done only by under a strong and coherent policy framework.

4.2 Private sector engagement

Private sector engagement can help Egypt to move towards a sustainable long-term approach to address food security concerns. This can also deliver an enhancement to existing, promising developments of increased export revenues. FAO (2022a) reported that the Egyptian horticulture sector generated USD 2.2 billion in export earnings for 2020, showing continued strength despite supply chain disturbances and doubts in global trade due to COVID-19. Egypt's fruit and vegetable

FIGURE 25. Greenhouse for palm seedlings production

sector is one of the country's fastest-growing agribusiness sectors. For some products such as oranges, Egypt is one of the biggest exporters in the world. Egypt's position as the main exporter makes it an attractive investment for the private sector.

Strengthening private sector engagement in the agrifood system can contribute positively to both quantity and quality of agricultural products across the supply chain and assist in building a strong, sustainable, and inclusive agribusiness sector. The Egyptian Government encourages new and innovative ways to engage with the private sector and to attract more targeted investments that can reduce the cost of Egypt's import bill. The private sector has the potential to play a major role in advancing climate-smart agricultural practices.

FIGURE 26. Private farm in Matrouh with desert aquaculture using desalinated ground water connected to drip irrigation system for olive, fig trees and vegetables

4.3 Role of the civil society organizations

Achieving CSA depends also on the engagement of civil society. The civil society organizations (CSOs), such as Non-governmental organizations (NGOs), farmers' organizations, and local communities can provide extension services, support local communities, and advocate for climate-smart agriculture policies. They can play a key role in raising awareness, facilitating fair trade agreements between exporting companies and local producers, marketing products for an advantageous price, and ensuring sustainable practices requirements are followed.

CSOs can also support families, provide social and community care, and provide loans to women to finance economic activities, such as animal and poultry production.

FIGURE 27. Field Drying tomato in Luxor

4.4 Women and youth involvement

The Country Gender Assessment of the Agriculture and Rural Sector in Egypt, developed by FAO in 2021, showed that women are very active in agriculture, especially in some regions of Egypt. However, women are often relegated to subordinate positions due to a rigid gender-based division of labour in agricultural tasks, household care and domestic responsibilities.

Women mostly provide unpaid contributions to family farms and businesses or work under precarious contracts at lower pay under poorer working conditions compared to men.

Despite progress in recent decades, women are not seen as independent, but as helpers and contributing family members. This situation means that women farmers invisible to institutions leading to a disconnect between the agricultural support services (extension, financial, social protection, or business development) and the needs of women in the agricultural sector. As a result, rural women do not have access to agricultural training, innovative practices and technologies, and market information. (FAO, 2021b).

Women are also excluded from crucial sectors such as water. Irrigation engineering is typically dominated by male engineers, who are the most visible professionals associated with this sector. In Egypt, water management is directly linked to land ownership: since women seldom own land and are rarely perceived as irrigators, they are almost never presented with opportunities to serve on or participate in irrigation management institutions (FAO, 2022b).

This gap affects how men and women perceive and experience the benefits of CSA. A gender-responsive approach is necessary and can be accomplished by recognizing the specific needs and capabilities of men and women and implementing appropriate site-specific practices for smallholder farmers (Nelson, 2016).

Nelson (2016) outlines five criteria for evaluating whether a gender-responsive approach is or should be used in a CSA practices:

1. The development and application have been informed by gender analysis;
2. Work has involved the participation of men and women and those who will implement the practice;
3. Efforts to reduce constraints to practice uptake;
4. Practice results have immediate benefits for men and women; and
5. Practice results in long-term benefits for men and women (Nelson, 2016).

A gender-responsive approach is most effective in tandem with an enabling environment, with clear, visible, and genuine political commitment with an awareness and understanding of gender issues. Significant attention must be placed on gender through financing and funding, participation, education, and staff capacity. Progress and results must be monitored and raising awareness on why gender equality matters within CSA should be carried out.

CSA practices are less effective without attention and intention to gender. A study in Kenya and Tanzania (nations facing similar climate and gender-related issues), assessed zero-grazing, reduced tillage, improved manure management, agroforestry, soil and water conservation, crop rotation, mulching, and improved cooking stoves. Data showed that the adoption rate of practices differed based on gender, where it shaped the capacity to implement climate-smart opportunities into the household (Rioux *et al.*, 2016). Specifically, to support an affective CSA approach, attention should be focused on:

- empowerment and education;
- equal access to and receiving of funding;
- equal access to and receiving of technology.

This report has outlined the importance of each practice as a mechanism for creating sustainable solutions for the climate crisis. However, CSA will not work without the main workforce (women) leading the way. Achieving broader CSA goals is dependent on strong leadership on gender equity by the Egyptian Government. The International Monetary Fund has estimated that if women in Egypt is have equal access to workforce opportunities, the GDP would increase by approximately 34 percent. This includes access to land, educational and instructional opportunities, and gender equity programmes.

BOX 3. Gender and improved irrigation techniques: Story of Amal

The New Valley Governorate faces increasing agricultural water scarcity and many farmers suffer from a lack of irrigation water, high levels of salinity in the water and soil, poor agricultural drainage, and sand creeping encroaching on irrigation canals and agricultural lands. FAO has organized farmer field schools in the El Kharga Oasis on how to use water more efficiently.

Amal participated in the FAO farmer field schools. Along with her sister, she is one of the few women in the El Kharga Oasis who owns land and cultivates it herself. Amal grows wheat and alfalfa as well as vegetables for household consumption in the winter, and peanuts in the summer. These crops require continuous irrigation.

After moving from Upper Egypt to the New Valley Governorate, Amal cultivated her land using the traditional flood irrigation method that her father had used in the old land. However, with water scarcity in the New Valley, her allocated flood irrigation water only reaches her field every ten days which is hardly enough to irrigate half of her land.

Through the FAO FFS, Amal learned how to use the advanced irrigation system as a solution to the challenge she faces. She decided to save from her previous income and paid 15,000 Egyptian pounds (EGP) to install an improved irrigation system. The new system helped her to cultivate all her lands using her limited water allocation and Amal was able to double her profits for the year.

Amal's farm has been used as a model for using the new successful irrigation technique. She is well-regarded by the members of her village and provides a good example of how to implement sustainable agriculture practices.

FIGURE 28. Woman irrigating her field in El Kharga

Source: Authors.

CHAPTER 5:
National programmes of relevance to climate-smart agriculture

The Egypt Government has developed a number of national structural interventions that contribute to making agriculture more resilient.

5.1 *Hayat Karima* initiative (Decent Life)

Hayat Karima "Decent Life" is an initiative aimed at enhancing the resilience of rural communities by improving the standard of living for the poorest rural communities. *Hayat Karima* seeks to reduce poverty rates by developing infrastructure and providing basic services, including education and health designed to meet the needs of rural populations. Women, youth, and people with disabilities are considered within the framework of the SDS.

The initiative has the following four main pillars (WFP, 2021):

1. improving living-standards and investing in human capital;
2. developing infrastructure services;
3. raising the quality of human development services;
4. boosting economic development (in particular, it provides the poorest villages with increased access to the basic services such as health, education, water and sanitation).

Launched in 2019, the initiative covers 4,500 villages targeting 50 million Egyptians with total investments of 500 billion Egyptian pound (EGP).

Hayat Karima is being undertaken in three phases depending on the village poverty rate, with the selection of the villages based on the poverty map developed in 2008. The first phase was launched in January 2019 and covered the poorest 377 villages (investments of EGP 7.5 billion). The second phase was launched in January 2021 covering 1 400 villages (investments of EGP 150 billion) with beneficiaries representing 20 percent of the overall Egyptian population (WFP, 2021).

5.2 *Bahr El Baqar* water treatment plant

Bahr El Baqar is a 106 km long drain that receives agricultural, industrial, and sewage wastewater from the Delta. It has been recognized as a serious source of pollution with adverse impacts on human health.

The recently established *Bahr El Baqar* wastewater treatment plant is part of the Suez Canal Region Development Plan in Sinai. The plant will treat the raw drainage water of the Bahr El Baqar drain (2 billion m^3/year), before it is discharged into the El-Sheikh Gaber Canal for irrigation purposes, contributing to the cultivation of 400 000 feddan. The plant will produce 5.6 million m^3/day of irrigation water and sludge using solar drying facilities with an annual capacity of 165 000 tonnes at 75 percent dryness level.

5.3 Lining irrigation canals

The network of open irrigation channels in Egypt is one of the largest and longest worldwide, at about 33500 km in length (Abuzeid, 2021). Earth channels result in water losses and difficulties for efficient and effective water management. Recent reports from the Ministry of Water Resources and Irrigation of Egypt show that canal lining is likely to be the most suitable solution for better managing water and enhancing agricultural productivity (Abdelaty *et al.*, 2022).

Rehabilitation of the Mesqua (a tertiary channel that receives water from the main channel) through the use of modern irrigation techniques is an ongoing national project, aiming to convert 3.7 million feddan of the Old Lands to modern irrigation within three years. To date 40 km of Mesquas have been rehabilitated and with a further 446 km to be rehabilitated in six governorates.

Studies have shown that transmission losses in the El-Sont canal in Middle Egypt (Assuit Governorate) and its off-taking canals were estimated at 39.54 million m^3/year. Such large quantities of saved or recovered water could be used for reclaiming and irrigating the additional 5,000 feddan in the nearby desert area (Ashour, 2021).

Lining irrigation canals can directly benefit their catchments in rural communities where agricultural fields had been continually waterlogged and properties damaged due to canal seepage and resulting increased groundwater levels. Lining the canal not only improves water management, but also reduces damage to communities and improves soil quality for sustainable agricultural production.

FIGURE 29. Lined irrigation canal in the Delta

5.4 The national project for Veal Revival

The national project for Veal Revival was established to achieve greater balance in the local meat market and reduce imported beef products. The project was funded more than EGP 6 billion to finance the feeding of 405 000 cattle.

This project aims to enhance sustainable livestock production through either increasing output (for example, increased milk and meat production) or decreasing inputs while maintaining the same output: for example, by using a higher quality of feed supplies. It is estimated that improving sustainable livestock productivity will reduce GHG emissions per unit of livestock product by 20 percent to 30 percent. Such estimates are based on evidence that specific livestock feed can lower GHG emissions (FAO. 2021c).

FIGURE 30. Enhancing livestock sustainable production through the national project for Veal Revival in Luxor

CHAPTER 6: Conclusions and recommendations

The main purpose of this report has been to identify, and document promising climate-smart agriculture (CSA) interventions and practices contributing to a more resilient agrifood system in Egypt. Although Egypt faces a combination of climate challenges from water scarcity to population growth and sea-level rise, sustainable and nature-based solutions are available and being implemented. CSA approaches can build resilience to these challenges and promote a more sustainable future.

These observations suggest that the implementation of CSA practices can be sustainably and practically applied in a variety of conditions, locations, and circumstances. Place-based solutions developed for site-specific contexts are critical for the effective implementation of CSA practices. Effective CSA is dependent on an enabling institutional environment, appropriate infrastructure, processes to ensure stakeholder engagement, measures to foster gender equality, and mechanisms to increase small-scale farmers' access to credit, insurance, extension and advisory services.

The scaling up of CSA requires strong political commitment capable of securing the necessary level of coordination among stakeholders across sectors including agricultural development, climate action and food security. All these elements must fit together to create a solid foundation that can allow CSA to be scaled up and achieve large-scale transformations of the food system.

Annex 1. Overview of technologies and practices identified in Egypt and their contribution to the three climate-smart agriculture pillars

Examples of technologies and practices.	**Sustainably increase agricultural productivity and incomes** 1 	**Adapt and build resilience of people and food systems to climate change** 2 	**Reduce and/or remove greenhouse gas emissions, where possible** 3 
Agronomic practices	**Sustainably increase agricultural productivity and incomes**	**Adapt and build resilience of people and food systems to climate change**	**Reduce and/or remove GHG emissions, where possible**
Use of bio-fertilization-(Okadine) replaces, partially or totally, the use of chemical nitrogen fertilizer.	Using Okadine saves 50% of the N fertilizer applied to crops, therefore reducing costs and increasing farmer income.	Contributes to enhancing and maintaining soil-fertility and quality. This, in the long term, prevent soil depletion, increase resilience and ensure productivity and farmer profit. Reduces soil and water pollution due to losses of chemical N fertilizers in form of leached nitrates.	Reduces use of chemical N fertilizers leading to less energy consumption and lower emissions of CO_2 and other GHGs due to N fertilizer production.
New varieties tolerant to heat, drought and salinity	Choosing crop species and varieties that are well adapted to climate change, allows continuity of farm productivity also by reducing loss of products, consequently maintaining steady productions and profits.	Significantly contributes to the adaptation of farming systems to prevalent and expected impacts of climate change such as drought, salinity and flooding. Increases the efficient use of water and nutrients resources. They contribute to enhancing the resilience of the farmers and the food system as a whole.	Rice, wheat and maize varieties that use fertilizers more efficiently will contribute to less GHG emission. Using early maturity rice varieties will significantly reduce methane emission from the rice cultivation.
Intercropping	Improves crop quantity and quality.	Provides economic insurance for farmers in case one crop fails.	Maintains or improves soil carbon stock or organic matter content.

	Maximizes the efficiency of use of natural resources, such as land, water, light, and nutrients. Diversifies cropping systems, contributing to the reduction of the risk of crop failure due to weather shock. It also increases food and feed availability, dietary diversity, farmers' income and human wellbeing.	Increases land-use efficiency. Reduces use of chemical fertilizer due to fixing atmospheric nitrogen, as in the case of legume and cereal intercropping. Controls weeds. Reduces soil erosion. Improves soil structure, therefore increasing water-holding capacity. Improves soil biodiversity therefore contributing to enhanced physical, chemical and biological characteristics of the soil.	Reduces the need for chemical fertilizer, therefore reducing GHG emissions derived from their production processes.
Cultivation on wide ridges	Increases the efficiency of natural resource use such as soil, water and nutrients, therefore resulting in higher yield. Reduces loss of products and the consequent reduction of income. Improves crop quantity and quality	Reduces growth of harmful weeds, save irrigation water, decrease amount of chemical fertilizers and pesticides required, ultimately saving soil quality. Reduces water requirements compared with conventional farming on rows.	Protects and conserves existing SOM. Stores more SOM than farms under conventional agricultural practices
Mulching	Allows soil to retain its moisture by shading the ground and reducing soil evaporation, resulting in higher water use efficiency. Protects soil from increasing of soil temperature. It is a natural solution for the increasing heat that is damaging plant productivity. Replenishes soil nutrients through its natural decay. Suppresses weeds germination and growth. As a result of the above, use of mulching sustainably increases agricultural yields. It is also a low-cost method, which combined with increased yields, will enhance farmer profit.	Reduces soil erosion, by protecting soil from rainfall and wind. Provides shelter from two unpredictable and threatening elements critical to agriculture: heat and water. Promotes food-system resilience by increasing water-use efficiency due to the slowing of natural evaporation. Works as a natural fertilizer through the natural decay of its organic matter. Allows for better yield resilience and higher nutrient uptake by plants. Leads to a significant decrease in accumulation of salts in the root zone under different irrigation treatments, therefore protecting soil quality.	Wood mulch has been found to cut NO_2 emissions by up to 28%. NO_2 is a GHG 300 times more potent than CO_2. Organic mulch works as an additional source of carbon for soil.

Sugar cane buds' chip for seedlings production	Saves about 96% of the sugar cane previously used as seeds by weight. Reduces cost of cultivation. Saves tonnes of raw material that can be used for extracting sugar rather than been buried in the soil as seed. Increases the average land productivity, from 33 to 55 tonnes per each feddan. Saves both resources and money, farmers have better use of time and land area: such benefits increase productivity, and farmer income.	Increases fertilizer-use efficiency, therefore reducing the need of chemical fertilizer by 35%. Allows saving about 30% of the irrigation water.	Reduces GHG emissions required for fertilizer production.
Protected agriculture	Increasing farm profitability by allowing for the cultivation of high-value crops (for example, horticultural crops, and fruits) due to effective protection against extreme weather events (for example, hail) and harsh environmental conditions. Reduces water consumption by more than 50% compared to open field production and increases yields between two and three times compared to open-field agriculture (FAO, 2021c).	Improves input use efficiency (for example, water, land, nutrients) and allows for the diversification of farm produce, ultimately contributing to communities' increased resilience and adaptive capacity.	Trade-offs: high cost for initial investment, which may vary depending on the type and size of protective measure adopted. Greenhouse systems can require high energy consumption (for example, for heating or refrigeration during the cold or warm season, artificial lighting), and the use of fertilizer and growing media, therefore resulting in higher GHG emissions compared to the BAU. Various measures can be adopted to reduce the impact of higher energy requirements for example, GHG emissions), such as maximum insulation, smart climate control, use of sustainable energy sources such as biogas, photovoltaics and geothermal energy (Grudaa, 2019).
Composting agricultural wastes and residues.	Converts organic waste to animal fodder, fish feed, organic fertilizers, and as a substitute for wheat straw in poultry farm bedding.	Increases SOM content, improving soil quality, soil nutrients and water-holding capacity, and increasing soil resilience.	Reduces the practice of burning directly in fields especially rice straw. Reduces the need for chemical fertilizers, and increases SOM.

	Producing and selling compost can diversify farmer income. Increase agricultural production, therefore improving food security and human wellbeing.		

Source: Authors.

Water saving techniques	**Sustainably increase agricultural productivity and incomes**	**Adapt and build resilience of people and food systems to climate change**	**Reduce and/or remove GHG emissions, where possible**
Shift to drip and sprinkler irrigation	Increases farm profitability through the effective use of labour, energy, and water. Efficient water use reduces costs and enhances productivity. Savings can be used for other purposes. More efficinte water use increases productivity.	Improves farmer resilience by supporting them in facing climate change impacts, such as prolonged drought periods. Reduces nutrients lost through leaching or runoff resulting from traditional surface irrigation (channels, flooding).	Drip irrigation can dramatically reduce GHG emissions from soil without sacrificing crop yields.
Advanced Irrigation Techniques	Increases farm profitability through the effective use of labour, energy, and water. Saving water in some areas helps farmers to cultivate more land and increase family income.	Improves farmer resilience through increased water use especially during water scarcity or drought.	Reduces energy used for pumping water, consequently reducing CO_2 emissions.
Water Users Associations	Increases farm profitability through the effective use of labour, energy, and water. Efficient water use reduces costs and enhance productivity. Savings can be used for other purposes. Using water only when necessary for biological and weather reasons helps farmers to increase productivity.	Improves community resilience by supporting them in facing climate change impacts, such as prolonged drought periods.	
Lining Branch Canals	Lining irrigation canals allows reduction of water consumption favouring an increase of income for families. It also favors reduction of the costs of maintenance and disinfection of waterways. Equitable distribution and enhancing the access of water to the end of the canals.	Better water management by preventing excess water seepage.	

Water Harvesting	Water harvesting enables crops or fodder to be grown despite inadequate rains, or outside growing seasons.	Increases farm resilience by increasing water availability and efficiency despite precipitation decrease and uncertainty due to climate change. Allows for diversification of cultivated crops. Reduces surface runoff and water loss, contributing to reduced soil erosion, and protecting the downstream villages.	Water harvesting can contribute to lower CO_2 emissions if solar energy is used in pumping the collected water rather than using conventional fossil fuel pumps.
Aquafarm and Aquaponics agriculture	Soil-less agriculture allows for the cultivation of high-value crops, highly efficient use of land, water and nutrients. It increases farmer income due to crop diversification, both in terms of type and time of produce availability.	Increases the efficiency of water, land and nutrients therefore increasing the resilience of farms and of the entire agrifood system.	Reduces the amount of fertilizer needed by reducing osses due to leaching or runoff. Reduces GHG emissions due to fuel use for mechanization. Trade-off for climate change mitigation: the automatic system to control temperature uses fuels, therefore producing GHG emissions.

Source: Authors.

Renewable energy	Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food systems to climate change	Reduce and/or remove GHG emissions, where possible
Converting livestock waste into biogas.	Diversifies farm production, increases access to clean energy source, and serves as an efficient strategy for agricultural waste and residues disposal.	Generates bioenergy and produces organic additions for small farmers, reducing their dependency on expensive fossil fuels and fertilizers.	Mitigates GHG emissions derived from the natural decay of agricultural waste (especially animal waste). Replaces energy from fossil fuel therefore working as a means for mitigation.
Solar pumping irrigation system (SPIS)	Reduces energy costs compared to the use of fossil fuels for pumping irrigation water. Provides a reliable and less expensive source of energy for farmers.	Enhances resilience of farming systems, facing fluctuation in availability and affordability of fossil fuels. Contributes to enhance the resilience of remote rural areas by providing reliable source of energy.	Reduces GHG emissions compared to the use of fossil fuels to pump irrigation water.

Source: Authors.

Annex 2. Interlinkages between agriculture intervention at the national level and the three pillars of climate-smart agriculture

Agriculture interventions at the national level	Sustainably increase agricultural productivity and incomes	Adapt and build resilience of people and food systems to climate change	Reduce and/or remove GHG emissions, where possible
Hayat Karima initiative (*Decent Life*).	Efficient use of natural resources reduces costs and enhances productivity and increases farm profitability. Increases agricultural production and improves food security and human wellbeing.	Improves resilience of farmers by supporting them in facing climate change impacts.	Mainstreams improved agricultural technologies that encourage reducing the use of chemical fertilizers. Adopting improved livestock production management can reduce GHG emissions.
Bahr El Baqar Treatment Plant	Increases agricultural production by adding new land for cultivation of 400 000 *feddan* in Sinai, improving food security and human wellbeing.	Increases farm resilience by increasing water availability and efficiency. Irrigation using treated drainage water reduces soil pollutants.	Reduces the need for chemical fertilizers, and increases SOM by producing sludge, using solar drying facilities with an annual capacity of 165 000 tonnes.
Lining irrigation canals	Lining irrigation canals allows reduction of water consumption and increases of income for families. Reduces the costs of maintenance and disinfection of waterways.	Prevents water seepage and increases water efficiency.	
The National Project for Veal Revival	Enhances sustainable livestock production by increasing outputs (for example, increased milk and meat production) and by using higher quality feed supplies.	Prevents water seepage and increases water efficiency.	Improves sustainable livestock productivity for example, by using higher quality of feed supplies, and will reduce GHG emissions. Trade-off for climate change mitigation The global livestock sector accounts for more GHG emissions than many other food sources. Including mitigation measures whenever possible can contribute to reduced emissions and enhanced climate resilience of the sector. Improved pasture management increases feed availability, as well as the amount of carbon sequestered in the soil of grasslands.

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