CLIMATE CHANGE
27/2025

Mitigating agricultural greenhouse gas emissions in Egypt

Status, potential and challenges

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Abstract: Egypt Country Report

This report describes the current state of agriculture in Egypt with regard to the greenhouse gas (GHG) emissions it produces and the climate and other socio-economic policies that it faces. We identify options that could reduce agricultural emissions and estimate the mitigation potential of those options. Finally, we identify barriers to adopting these mitigation strategies and some possible solutions to overcoming those barriers.

Kurzbeschreibung: Länderbericht Ägypten

Dieser Bericht beschreibt den aktuellen Stand der Landwirtschaft in Ägypten im Hinblick auf die von ihr verursachten Treibhausgasemissionen (THG-Emissionen) und die klimapolitischen und anderen sozioökonomischen Maßnahmen, denen sie ausgesetzt ist. Wir identifizieren Optionen, die die landwirtschaftlichen Emissionen reduzieren könnten, und schätzen das Minderungspotenzial dieser Optionen. Abschließend werden die Hindernisse für die Einführung dieser Minderungsstrategien und einige mögliche Lösungen zur Überwindung dieser Hindernisse aufgezeigt.

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List of abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AWD	Alternate Wetting and Drying
BEFs	Bioenergy from residues
BUR	Biennial Update Report
CHP	Combined heat and power
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COAE	Center of Organic Agriculture in Egypt
DAIRS	Dynamic Agriculture Information and Response System
ECOA	Egyptian Center for Organic Agriculture
EEAA	Egyptian Environmental Affairs Agency
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse gas
ha	Hectare
IFAD	International Fund for Agricultural Development
IFOAM	International Federation of Organic Agriculture Movements
iNDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
K	Potassium
kg	Kilogramme
km^2	Square kilometre

AFOLU	Agriculture, Forestry and Other Land Use
kWh	Kilowatt-Hour
LE	Egyptian Pounds
LPG	Liquified Petroleum Gas
LULUCF	Land Use, Land Use Change, and Forestry
MALR	Ministry of Agriculture and Land Reclamation
MoE	Ministry of Environment
MSD	Mid-season drainage
Mt	Megatonne
MtCO2e	Mega tonnes of CO_2 equivalents
MW	Megawatt
MWRI	Ministry of Water Resources and Irrigation
N	Nitrogen
NAP	National Adaptation Plan
NCCC	National Council for Climate Change
NCCS	National Climate Change Strategy (2050)
NDC	Nationally Determined Contribution
NH_3	Ammonia
NUE	Nitrogen Uptake Efficiency
N_2O	Nitrous oxide
P	Phosphorus
PV	Photovoltaic
RCREEE	Regional Centre for Renewable Energies and Energy Efficiency
REMENA	Renewable Energy and Energy Efficiency for the Middle East and North Africa Region
SADS	Sustainable Agricultural Development Strategy
SAIL	Sustainable Agriculture Investments and Livelihoods
SDS	Sustainable Development Strategy
SMR	Steam Methane Reforming
THG	Treibhausgas
UK	United Kingdom
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
USDA	United States Department of Agriculture
WUAs	Water User Associations
3-NOP	3-nitrooxypropan

Summary

The aim of this report is to identify possible emissions mitigation options in the agricultural sector, the barriers towards implementing those options and provide some recommendations on how to overcome those barriers. The report begins with a description of the current state of agriculture in Egypt with regard to the GHG emissions it produces, and the climate and socio-economic policies that shape the sector. We then identify three key options that could reduce agricultural emissions and estimate their mitigation potential. Other mitigation options are briefly discussed as well. Finally, we identify barriers that act at the farm, national, international and consumer level along with possible steps to overcoming those barriers.

The agricultural sector in Egypt is highly diversified with sugar cane, sugar beet, wheat and maize being significant products (Statista 2022). Egypt's agricultural sector accounts for a relatively small portion of the country's land use, since the vast majority of the country area is desert land (FAO 2016). In the period 2009-2016, less than 4% of the total land area was used for agriculture. Nevertheless, agriculture is considered an important economic sector: the agricultural sector contributes 11% to the country's gross domestic product (GDP), generates valuable export revenues and provides 21% of national employment.

The agricultural sector accounts for approx. 11% of Egypt´s national emissions (Gütschow et al. 2021), equating to 38 mega tonnes of CO_2 equivalents ($MtCO_2e$) in 2019, excluding Land Use, Land Use Change, and Forestry (LULUCF). The largest agricultural emissions sources include enteric fermentation (33%), synthetic fertiliser (20%), rice cultivation (17%), manure left on pasture (14%) and on-farm energy use (11%). There are no designated pastures, since livestock is either kept in stables, in the yard, or on land with fodder that is used to grow food crops in other seasons. Livestock production in Egypt makes up 42% of the total value of agricultural production (Tanyeri-Abur 2015). Water and food security are key policy goals in Egypt as Egypt's agriculture and thus food security almost fully depends on continued Nile water flows and is highly vulnerable due to erosion, saltwater intrusion and flooding events (Global Alliance for the Future of Food 2022).

In 2019, Egypt produced 4.2 million tonnes of nitrogen fertiliser, of which more than half were exported (FAO STAT 2021). Egypt is the largest nitrogen fertiliser consumer in Africa (El Gharous and Boulal 2016) while it has a low nitrogen use efficiency (FAO STAT 2021). Another important driver of growing emissions related to agriculture are population and economic growth, as well as diets changing to include more nitrogen intensive agricultural products, such as red meat and cereals (Dawoud 2005). The largest source of livestock emissions in Egypt is buffalo, which makes up almost half of enteric fermentation emissions. The on-farm energy use in Egypt mainly derives from diesel pumps to channel and distribute irrigation water (El-Gafy and El-Bably 2016).

Three mitigation options were identified for detailed analysis based on the contribution of different emission sources, the potential for socio-economic and environmental co-benefits, the country-specific context of the agricultural sector, and the general feasibility for implementation.

For Egypt, we selected the following three mitigation measures:

- Improved fertiliser/nutrient management
- Shifting to non-continuous irrigation for rice cultivation
- Decarbonising on-farm energy use.

The implementation of the three selected mitigation options could contribute to an overall emission reduction of 1–7 $MtCO_2e$/year in the agricultural sector and up to 7.6 $MtCO_2e$/year in the energy sector. This leads to an overall potential in the range of 8–14.6 $MtCO_2e$/year, corresponding to 2–4% of Egypt's total GHG emissions in 2019. In addition to the mitigation measures described in detail here, improving animal feed and health, decarbonising the production of synthetic fertilisers and shifting from N-intensive diets and reducing food waste could help to further reduce emissions related to agriculture in Egypt.

There are critical barriers that hinder the implementation of measures to achieve the outlined mitigation potentials and impair other activities to reduce GHG emissions in the agricultural sector. Farmers face substantial up-front costs in implementing mitigation measures and need some financial support, even for measures that have long-term economic benefits. Additionally, there is a lack of knowledge and awareness among farmers that hinder a change of agricultural practices. A strategic vision and commitment to quantifiable emission reduction targets for the agricultural sector and policy incentives for more sustainably practices are lacking in Egypt. Also, reliable data for making the best investment and impact monitoring remain to be developed.

To accelerate the uptake and implementation of the measures described in this report, it is key to 1) enhance the national climate mitigation framework in agriculture, 2) in turn ensure that all agricultural policies are aligned with mitigation objectives and 3) implement sector policies to comprehensively address the areas where most mitigation is possible. These include incentives to reduce nitrogen fertiliser use, save water and replace diesel pumps with solar power irrigation systems. Training and financial support is necessary to provide farmers with the necessary equipment and knowledge to implement mitigation measures. Particularly, microfinance, access to technology, as well as maintenance and repair services or trainings would help to increase the spread of solar irrigation pumps. Small-scale solar-powered irrigation stations would help to encourage small-holder farmers to adopt this technology in their traditional surface irrigation (Morshedy 2022). These mitigation policies and incentives should also foster co-benefits between adaptation and mitigation in the agricultural sector, e.g. by reducing water needs, improving soil health and thus contributing to the national targets of food and water security.

Zusammenfassung

Ziel dieses Berichts ist es, mögliche Optionen zur Emissionsminderung im Landwirtschaftssektor zu identifizieren, die Hindernisse für die Umsetzung dieser Optionen aufzuzeigen und einige Empfehlungen zur Überwindung dieser Hindernisse zu geben. Der Bericht beginnt mit einer Beschreibung des aktuellen Zustands der ägyptischen Landwirtschaft im Hinblick auf die von ihr produzierten Treibhausgasemissionen und klima- und sozioökonomische Politik. Anschließend werden drei wichtige Optionen zur Verringerung der Emissionen, die im Zusammenhang mit der Landwirtschaft stehen, aufgezeigt und ihr Minderungspotenzial abgeschätzt. Auch andere Minderungsmaßnahmen werden kurz erörtert. Abschließend werden Hindernisse auf betrieblicher, nationaler, internationaler und Verbraucherebene sowie mögliche Schritte zur Überwindung dieser Hindernisse aufgezeigt.

Der ägyptische Agrarsektor ist stark diversifiziert; wichtige Produkte sind Zuckerrohr, Zuckerrüben, Weizen und Mais (Statista 2022). Auf den ägyptischen Agrarsektor entfällt ein relativ kleiner Teil der Landnutzung des Landes, da der Großteil des Landes Wüste ist (FAO 2016). Im Zeitraum 2009-2016 wurden weniger als 4 % der gesamten Landfläche für die Landwirtschaft genutzt. Dennoch gilt die Landwirtschaft als wichtiger Wirtschaftszweig: Der Agrarsektor trägt 11 % zum BIP des Landes bei, generiert wertvolle Exporteinnahmen und stellt 21 % der nationalen Arbeitsplätze.

Auf den Agrarsektor entfallen rund 11 % der nationalen Emissionen Ägyptens (Gütschow et al. 2021), was im Jahr 2019 38 MtCO_2e entspricht, ohne LULUCF. Zu den größten landwirtschaftlichen Emissionsquellen gehören die enterische Fermentation (33 %), synthetische Düngemittel (20 %), der Reisanbau (17 %), die Ausbringung von Dung auf Weiden (14 %) und die Energienutzung in landwirtschaftlichen Betrieben (11 %). Es gibt keine ausgewiesenen Weiden, da das Vieh entweder in Ställen, auf dem Hof oder auf Futterflächen gehalten wird, die in anderen Jahreszeiten für den Anbau von Nahrungsmitteln genutzt werden. Viehwirtschaft trägt 42% zum Gesamtwert der landwirtschaftlichen Erzeugung bei (Tanyeri-Abur 2015). Wasser- und Ernährungssicherheit sind zentrale politische Ziele in Ägypten, da die ägyptische Landwirtschaft und damit die Ernährungssicherheit fast vollständig von den Nilwasserströmen abhängt und aufgrund von Erosion, Salzwasserintrusion und Überschwemmungen sehr vulnerabel für die Auswirkungen des Klimawandels ist (Global Alliance for the Future of Food 2022).

Im Jahr 2019 produzierte Ägypten 4,2 Millionen Tonnen Stickstoffdüngemittel, von denen mehr als die Hälfte exportiert wurde (FAO STAT 2021b). Ägypten verbraucht die größte Menge Stickstoffdünger in Afrika (El Gharous und Boulal 2016) und weist gleichzeitig eine geringe Stickstoffnutzungseffizienz auf (FAO STAT 2021). Eine weitere wichtige Triebkraft für die Emissionen im Zusammenhang mit der Landwirtschaft sind das Bevölkerungs- und Wirtschaftswachstum sowie Ernährungsgewohnheiten hin zu einem höheren Anteil an rotem Fleisch und Getreide, d. h. an N-intensiven Agrarprodukten (Dawoud 2005). Die größte Emissionsquelle in der ägyptischen Viehwirtschaft ist die Büffelhaltung, auf die fast die Hälfte der Emissionen aus Gärungs- und Verdauungsprozessen entfällt. Der Energieverbrauch in landwirtschaftlichen Betrieben in Ägypten stammt hauptsächlich von Dieselpumpen zur Bewässerung der Felder (El-Gafy und El-Bably 2016).

Auf der Grundlage des Beitrags der verschiedenen Emissionsquellen, des Potenzials für positive sozioökonomische und ökologische Auswirkungen, des länderspezifischen Kontexts des Agrarsektors und der generellen Durchführbarkeit wurden drei Minderungsoptionen für eine detaillierte Analyse ausgewählt.

Für Ägypten haben wir die folgenden drei Minderungsmaßnahmen ausgewählt:

- Verbesserung des Düngemittel-/Nährstoffmanagements
- Umstellung auf nicht-kontinuierliche Bewässerung im Reisanbau
- Dekarbonisierung des Energieeinsatzes in landwirtschaftlichen Betrieben.

Die Umsetzung der drei ausgewählten Minderungsoptionen könnte zu einer Gesamtemissionsreduzierung von 1-7 $MtCO_2e$/Jahr im Agrarsektor und bis zu 7,6 $MtCO_2e$/Jahr im Energiesektor beitragen. Daraus ergibt sich ein Gesamtpotenzial im Bereich von 8-14,6 $MtCO_2e$/Jahr, was 2-4 % der gesamten Treibhausgasemissionen Ägyptens im Jahr 2019 entspricht. Zusätzlich zu den hier detailliert beschriebenen Minderungsmaßnahmen könnten die Verbesserung der Tierernährung und der Tiergesundheit, die Dekarbonisierung der Produktion von synthetischen Düngemitteln und die Reduzierung von Tierprodukten in der Ernährung sowie weniger Lebensmittelverschwendung dazu beitragen, die mit der Landwirtschaft in Ägypten verbundenen Emissionen weiter zu reduzieren.

Es gibt kritische Barrieren, die die Umsetzung von Maßnahmen zur Erreichung der skizzierten Minderungspotenziale behindern und andere Aktivitäten zur Verringerung der Treibhausgasemissionen im Agrarsektor beeinträchtigen. Die Landwirtinnen und Landwirte haben erhebliche Vorlaufkosten für die Umsetzung von Minderungsmaßnahmen und benötigen finanzielle Unterstützung, selbst für Maßnahmen, die langfristige wirtschaftliche Vorteile haben. Außerdem mangelt es den Landwirten an Wissen und Bewusstsein, was eine Umstellung der landwirtschaftlichen Praktiken behindert. In Ägypten fehlt es an einer strategischen Vision und an der Verpflichtung zu quantifizierbaren Emissionsreduktionszielen für den Agrarsektor sowie an politischen Anreizen für nachhaltigere Bewirtschaftungsmethoden. Auch verlässliche Daten für eine optimale Investitionsentscheidung und das Monitoring von Auswirkungen von Politikmaßnahmen müssen erst noch entwickelt werden.

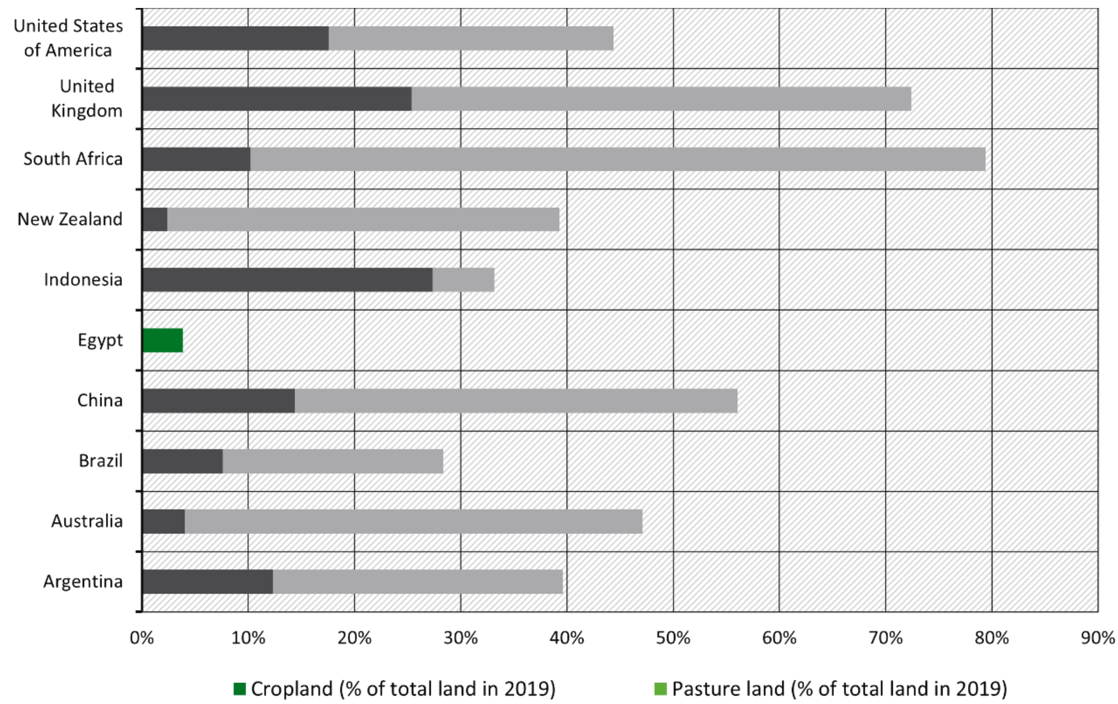
Um die Übernahme und Umsetzung der in diesem Bericht beschriebenen Maßnahmen zu beschleunigen, ist es von entscheidender Bedeutung, 1) den nationalen Rahmen für den Klimaschutz in der Landwirtschaft zu verbessern, 2) im Gegenzug sicherzustellen, dass alle agrarpolitischen Maßnahmen mit den Zielen des Klimaschutzes in Einklang gebracht werden, und 3) sektorale Klimaschutzmaßnahmen umzusetzen. Dazu gehören Anreize zur Verringerung des Einsatzes von Stickstoffdünger, zum Wassersparen und zum Ersatz von Dieselpumpen durch solarbetriebene Bewässerungssysteme. Trainings und finanzielle Unterstützung sind notwendig, um den Landwirtinnen und Landwirten die nötige Ausrüstung und das Wissen für die Umsetzung von Minderungsmaßnahmen zu vermitteln. Insbesondere Mikrofinanzierung, Zugang zu Technologie sowie Wartungs- und Reparaturdienste und Trainings würden dazu beitragen, die Verbreitung von solaren Bewässerungspumpen zu erhöhen. Kleine solarbetriebene Bewässerungsstationen würden dazu beitragen, Kleinbäuerinnen und -bauern zu ermutigen, diese Technologie bei ihrer traditionellen Oberflächenbewässerung einzusetzen (Morshedy 2022). Diese Maßnahmen und Anreize zum Klimaschutz sollten auch den gemeinsamen Nutzen von Anpassung und Emissionsminderung im Agrarsektor fördern, z. B. durch die Verringerung des Wasserbedarfs sowie die Verbesserung der Bodengesundheit und damit einem Beitrag zu den nationalen Zielen der Ernährungs- und Wassersicherheit.

1 General characteristics of the agricultural sector and policy landscape[1]

1.1 Characteristics of the agriculture sector in Egypt

Egypt is the third most populous country in Africa with 99.2 million people (IFAD 2021). The Egyptian agricultural sector accounts for a relatively small extent of the country´s land use. The cultivated area in Egypt in 2009-2016 ranged from 3.6-4.0 million hectare (ha) (Science of The Total Environment 2021) which corresponds to less than 4% of the total land area (see Figure 1). The vast majority of the country area is desert land (FAO 2016), so that the potential to expand cropland is very limited. Nevertheless, the Government of Egypt announced plans in 2014 to reclaim 4 million acres of desert land for agricultural purposes (Government of Egypt 2019). The "old" agricultural lands around the Nile Delta and Valley make up around 85% of Egypt's cultivated area and are largely managed by small scale farmers. The "New Lands" on reclaimed desert land are cultivated by both small scale farmers and larger commercial farms (IFPRI 2018).

Figure 1: Agricultural land as a share of total country area (2019)



Source: FAO (2022b) data for all countries. Data includes "Cropland" and "Land under permanent meadows and pastures"

There are no designated pastures, since livestock is either kept in stables, in the yard or on land with fodder that is used to grow food crops in other seasons.

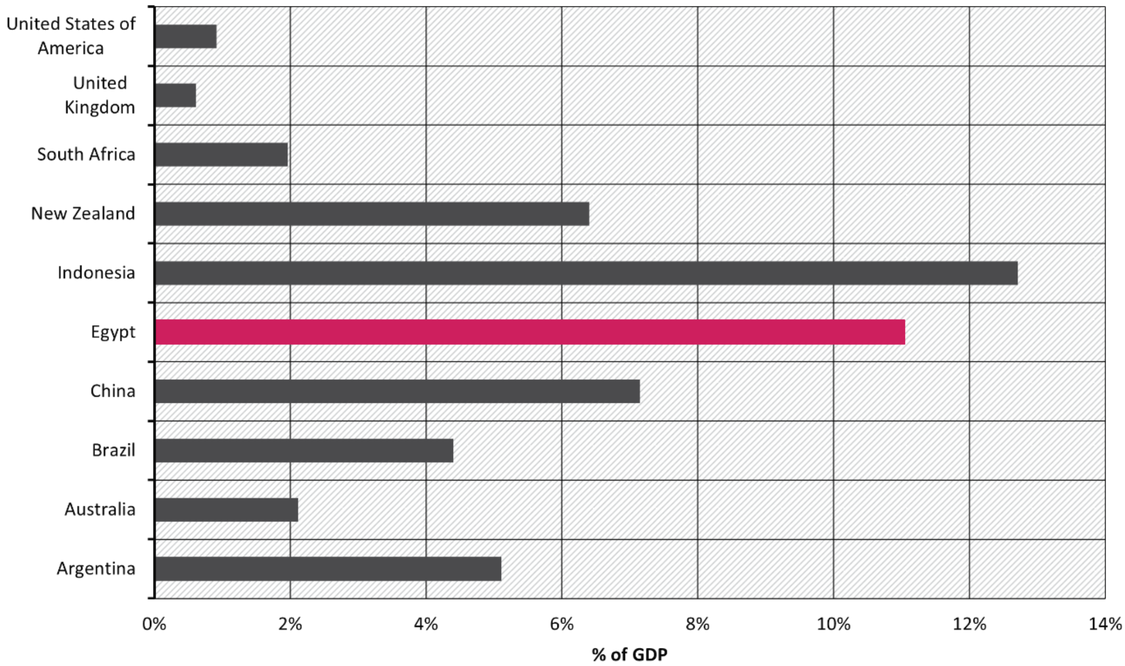
The agricultural sector in Egypt is highly diversified with sugar cane, sugar beet, wheat and maize being significant products (Statista 2022). In Egypt, agricultural land is cultivated in two

[1] The authors would like to extend special thanks to Mr. Saher Ayyad, a PhD candidate at the University of Bonn focusing on Water and Land Resources Management, for his thorough proofreading and expert contributions to the report. We would also like to thank Mr. Moharam (Assistant Professor of Animal Nutrition Faculty of Agriculture, Damanhour University) and Dr. Morshedy (Irrigation Agronomist, Land and Water Specialist at Ministry of Agriculture and Land Reclamation of Egypt) for providing their expertise to this report.

(winter, summer) and sometimes three (Nili) seasons, in addition to perennial crops that are cultivated throughout the year. Egypt's annual precipitation is low, so Egyptian agriculture is almost (97%) fully irrigated (El-Marsafawy and Mohamed 2021; Abdelkader et al. 2018; FAO 2011; 2017a). High temperatures and sandy soils require frequent irrigation (El-Marsafawy and Mohamed 2021; American University in Cairo 2021; FAO 2005). Typically, irrigation water is lifted to farmers' fields first through governmental pumping stations and then by farmers' diesel pumps, implying an energy intensive water supply to sustain the year-round production (El-Gafy and El-Bably 2016; USAID 2021). According to estimates, 86% of total water volumes consumed in Egypt is dedicated to agriculture (Elbasiouny and Elbehiry 2020).

The agricultural sector contributed approx. 11% to Egypt's gross GDP in 2019 (Figure 2) which is well-above the global average of 3.5% (OECD 2021). The agri-food sector is also a valuable source of foreign earnings for Egypt, accounting for 20% of export revenues (IFAD 2021). Livestock production in Egypt makes up 42% of the total value of agricultural production (Tanyeri-Abur 2015). Buffalo production makes up 25% of agriculture's contribution to GDP (Abdel-Salam and Fahim 2018).

Figure 2: Agriculture, fisheries, and forestry's contribution to GDP (2019)



Source: World Bank (2022) data for all countries except New Zealand due to lack of data. Value for New Zealand was taken from OECD (2021)

Egypt is the largest importer of wheat worldwide, heavily subsidising the staple crop to ensure food security. Egypt also imports rice, maize, frozen meat, dairy products, refined sugar and vegetable oil. At the same time, Egypt is a large exporter of vegetables and fruits. Agricultural exports annually grow at rates between 2-4.3% (IFPRI 2021).

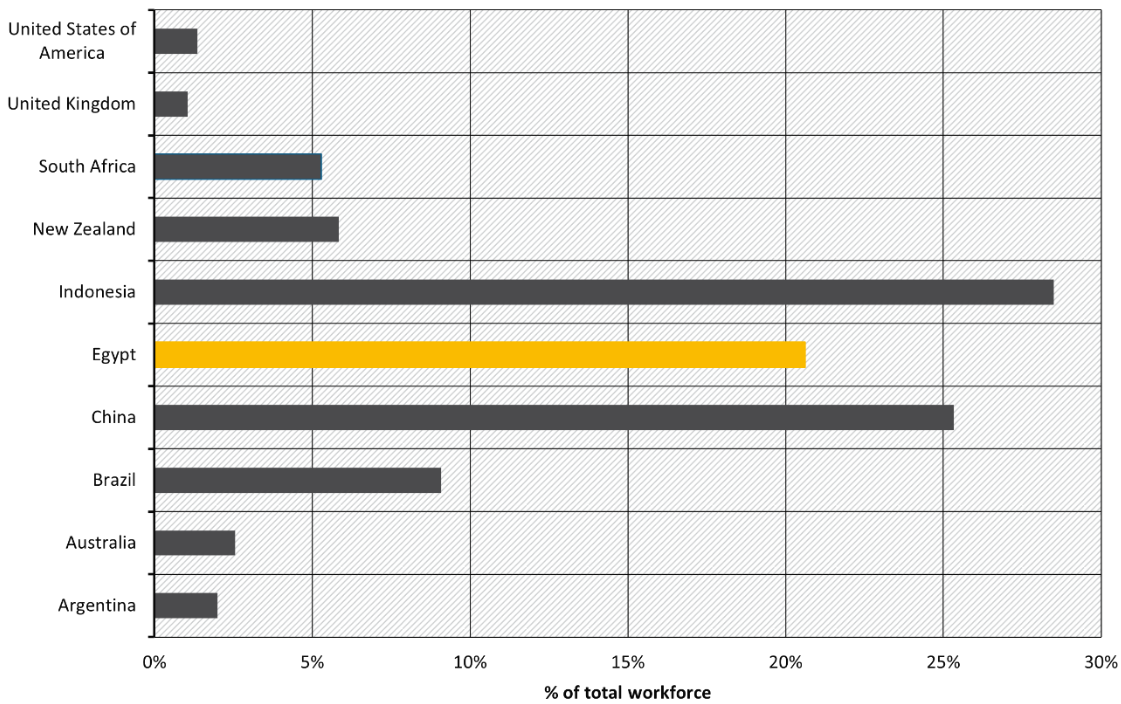
1.2 Socio-economic dimensions

Formal employment in the agricultural sector is high compared to other countries in the region, making up 21% of Egypt's total workforce in 2019 (Figure 3). According to Egypt's first Biennial Update Report submitted in 2019, the agricultural sector plays an important role for the

Egyptian economy by providing food, fibre and other products. Agriculture provides livelihoods for approx. 55% of the population (Government of Egypt 2019). Overall, the agricultural sector is dominated by small farms (USAID 2021).

Livestock plays an important role; while intensive cattle systems are run as large and modern businesses, semi-intensive systems are typically smaller family businesses with partly modernised infrastructure and practices. Intensive livestock production systems in Egypt make up 7% of cattle heads, semi-intensive 60% and extensive, small, mixed-crop-livestock farms account for 33% of cattle herds (FAO 2018). For extensive systems and thus large parts of the rural population in Egypt, the milk and meat of their cattle is an important source of income and protein in their diets. Fodder production, especially berseem (Egyptian clover) is an important part of soil fertility management in most smallholder and extensive cattle farms. Some smallholders are shifting towards tree plantations and transition away from livestock production as soon as their trees yield fruits (Aboul Naga et al. 2020). Diversification in farm activities and crops cultivated strengthens the economic resilience of and nutritional diversity available to Egyptian farm households.

Figure 3: Agricultural employment as a share of total workforce (2019)



Source: World Bank (2021) data for all countries except Argentina due to data discrepancy. Value for Argentina was taken from ILO (2021)

Egypt faces the double burden of malnutrition and obesity (Global Alliance for the Future of Food 2022): on one hand, over 75% of the population is enrolled in food subsidy programmes and acquire food at non-market prices (Abdelkader et al. 2018). In 2020, 5.4% of the Egyptian population was classified as undernourished (Knoema 2022). On the other hand, the number of obese adults in Egypt increases and, in 2019, amounted to approx. 40%, indicating imbalanced diets, largely relying on staple crops (Aboulghate et al. 2021).

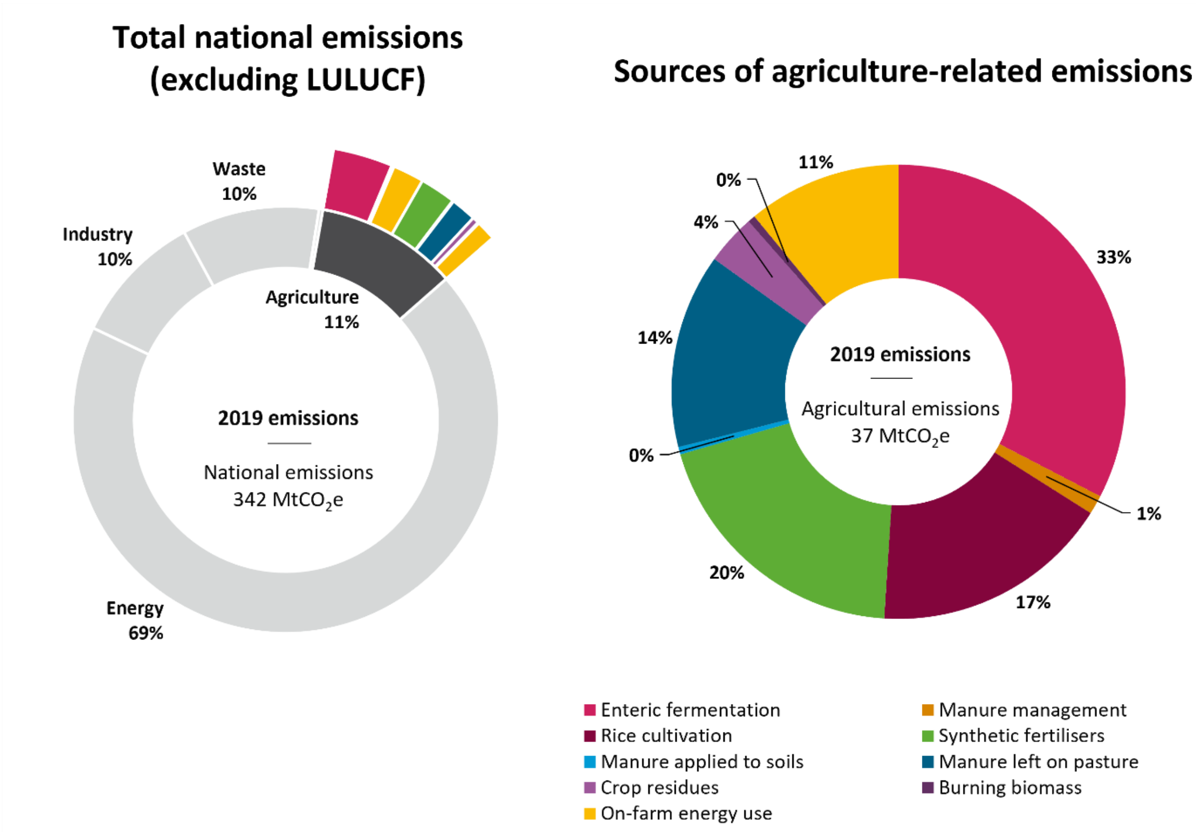
The high poverty rates, food import dependencies and transboundary water dependencies explain Egypt's development focus on water and food security. Close to 30% of Egypt's population were below the national poverty line in 2020 (Government of Egypt 2022). The

Egyptian government supports agricultural production by fuel and fertiliser subsidies (IFPRI 2020) and by organising the water supply for intensive irrigation (Fanack 2018). Rice, as grown in Egypt today, is a crop with a high water demand (see section 2.4), but is popular with farmers due to the relative ease in cultivation, the low production cost, the high profitability and good grain storability (Elbasiouny and Elbehiry 2020).

1.3 Greenhouse gas emissions from agriculture, forestry and other land use (AFOLU) and the man drivers

The agricultural sector accounts for around 11% of Egypt's national emissions, equating to 38 $MtCO_2e$ excluding LULUCF (Figure 4). The largest agricultural emissions sources include enteric fermentation (33%), synthetic fertiliser (20%), rice cultivation (17%), manure left on pasture (14%) and on-farm energy use (11%). Enteric fermentation and manure left on pasture jointly make up about 48% of Egypt's agricultural GHG emissions, making livestock production an emission hotspot of Egypt (FAO 2022a).

Figure 4: Egypt's GHG emissions profile (2019)



Source: Gütschow et al. (2021) for energy (excl. on-farm energy use), industry, waste, and other sectors. FAO (2022a) for agriculture and agriculture-related emissions.[23]

[2] The PRIMAP-hist dataset used for all non-agriculture-related emissions combines multiple datasets but prioritises country-reported data (Gütschow et al. 2021; Gütschow et al. 2016). FAO data may differ from nationally reported agricultural emissions under the UNFCCC, and thus agricultural emissions reported under PRIMAP-hist, as a result of data uncertainties and differing methodological approaches to reporting emissions in this sector. We use FAO for these graphs for non-Annex I countries since it includes a complete time series from 1990 to 2019, has a higher level of detail for non-Annex 1 countries (e.g. enteric fermentation emissions per category of animal), and maintains consistency across the assessed countries.

[3] While on-farm energy use is generally reported under the energy sector emissions for both PRIMAP-hist (Gütschow et al., 2021) and national data, we include it as an agriculture-related emissions source in this study because it is part of agricultural production

Drivers of these emissions are population and economic growth as well as dietary shifting towards more red meat and cereals, i.e. N-intensive agricultural products (Dawoud 2005). Cattle production, with 8.1 million heads, makes up the largest share of livestock-related GHG emissions in Egypt (UNFCCC 2005; IPCC 2006; Robertson et al. 2020).

Concerning GHG emissions from the production and application of synthetic fertiliser, in 2019, Egypt produced 4.2 million tonnes of nitrogen fertiliser[4], of which more than half (2.1 million tonnes) were exported, making exports an important driver for local fertiliser production. In 2019, 1.2 tonnes of fertiliser (319 kg/ha) were applied on Egyptian fields, generating about 0.02 Mt of direct and 0.006 Mt of indirect nitrous oxide emissions (N_2O emissions) (FAO STAT 2021). With such high average rates, Egypt is the largest consumer of fertiliser in Africa (El Gharous and Boulal 2016). N-inputs to croplands increased by 125% between the 1970s and the 2020s (Elrys et al. 2019), mainly due to the introduction of high yielding rice, wheat, maize and potatoes (ERF 2016). The Nitrogen Use Efficiency (NUE) in Egyptian agriculture decreased from 73% (1960s) to 43% (2019) (FAO STAT 2021).

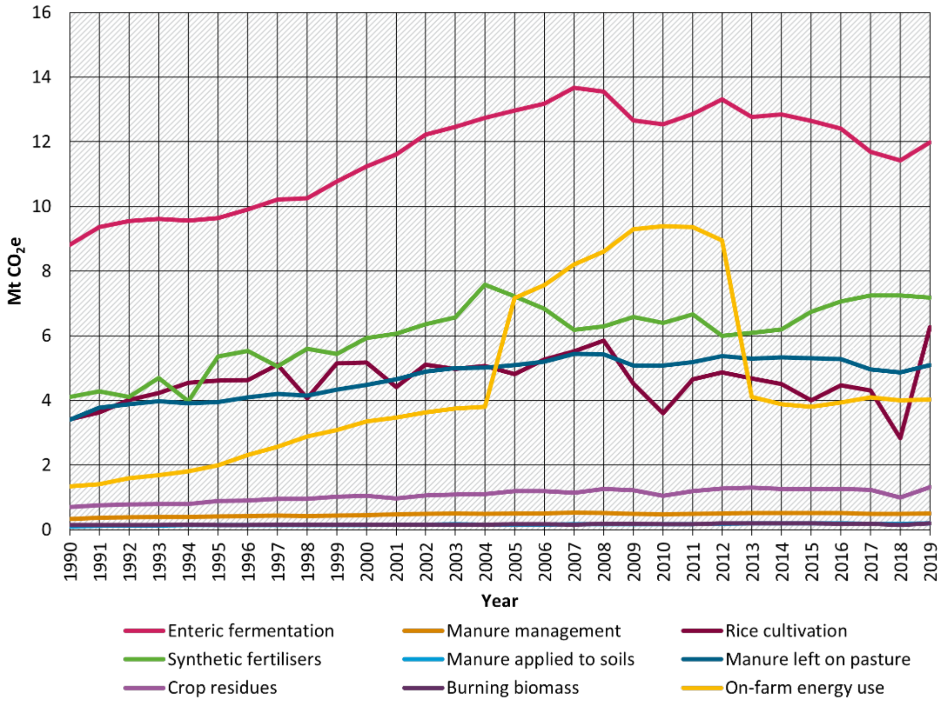
Emissions from rice cultivation make up about 17% of Egypt's national agricultural GHG emissions (Gütschow et al. 2021). Egypt is a major rice producer with production having increased by 81% between 1980 and 2000 (Dawoud 2005). Commonly, rice is cultivated intensively under continuous flooding in Egypt. Rice is grown in the Nile Delta as a summer crop, usually in rotation with cotton and maize (El-Shahway et al. 2016; Elbasiouny and Elbehiry 2020).

The on-farm energy use emissions in Egypt mainly come from the diesel pumps used to channel and distribute irrigation water (El-Gafy and El-Bably 2016) but also from agricultural machinery (e.g. ploughs), processing machines (e.g. threshers) and the transportation of produce and inputs to and away from farms.

(fuel use in harvesters, stable heating, grain drying etc.) and its relevance in several countries in terms of magnitude and mitigation potential. We refer to 2019 instead of 2020 data which was the latest data available at the time of writing, due to COVID-related economic dynamics that affected national emissions in 2020.

[4] According to Statista (2023), Egypt was the sixth largest producer of nitrogen fertiliser worldwide in 2018.

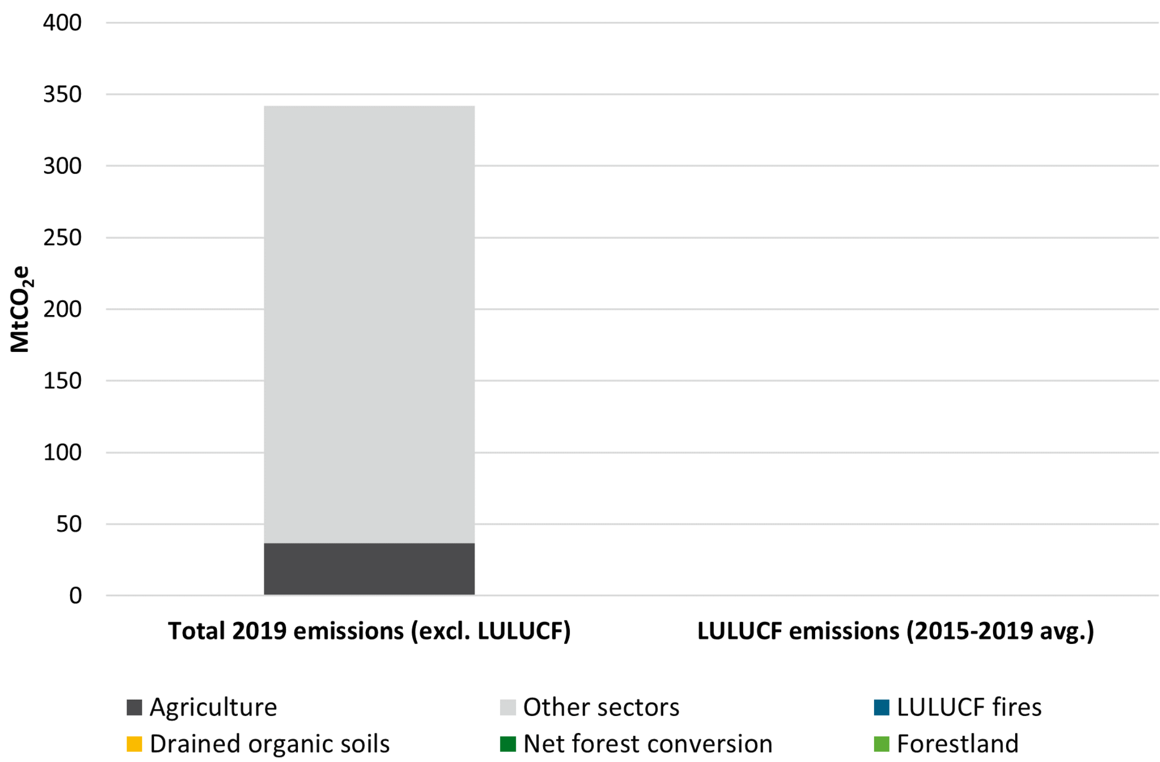
Figure 5: Agriculture-related emissions in Egypt (1990–2019)



Source: FAO (2022a)

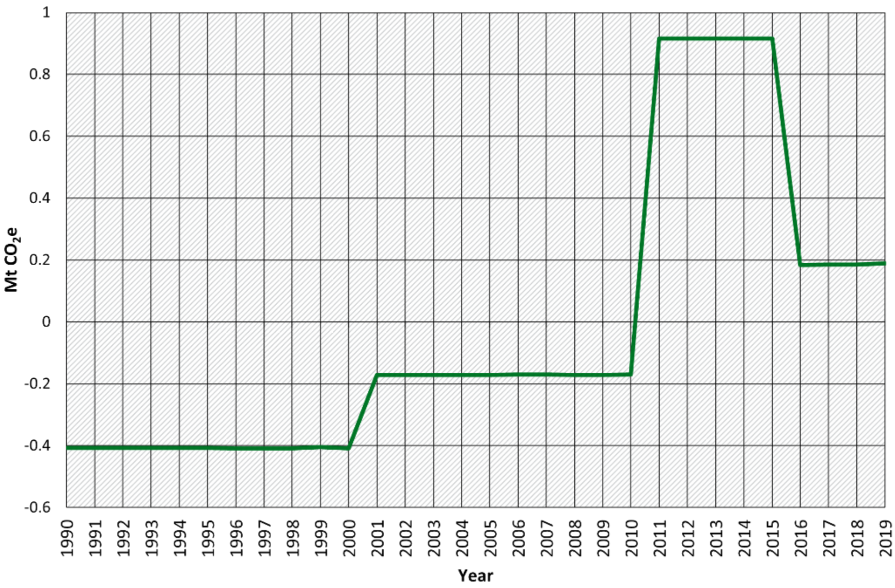
There are no significant Land Use, Land Use Change and Forestry (LULUCF) activities in Egypt, accounting for 0.2 Mt CO_2e (less than 1%) of Egypt's total emissions in 2019 (Figure 6, Figure 7).

Figure 6: Egypt's land use, land use change and forestry (LULUCF) emissions (average over the period 2015–2019) relative to total national emissions in 2019 (excl. LULUCF)



Source: Gütschow et al. (2021) for emissions from 'Other sectors' (energy excl. on-farm energy use, industry, waste, and other emissions). FAO (2022a) for agriculture-related and LULUCF emissions. LULUCF fires includes the FAO categories "Forest fires," "Fires in humid tropical forests," and "Savanna fires"[5].

Figure 7: LULUCF emissions in Egypt (1990–2019)



Source: FAO (2022a). Includes FAO categories "Forestland," "Net forest conversion," "Forest fires," "Fires in humid tropical forests," "Forest fires," "Savanna fires,"[5] and "Drained organic soils." Note that FAO data differs from national data and uses forest activity data in 5-year intervals, meaning data is averaged over the 5-year periods and can highly fluctuate between those intervals. This report uses FAO data for consistency with the other non-Annex I countries in this report series.

1.4 Government structures and agricultural policy framework

In 2015, Egypt established the National Council for Climate Change (NCCC), leading Egypt's NAP (National Adaptation Plan) process (UNDP NAP-GSP 2018). In 2017, an Adaptation Task Force was established and Egypt submitted its first iNDC (Arab Republic of Egypt 2017; UNDP NAP-GSP 2018; Ministry of Environment 2018) which is linked to the national Sustainable Development Strategy (SDS) with a vision for 2030 (MPED 2020). Additionally, Egypt published a National Climate Change Strategy 2050 (NCCS),[6] a National Strategy for Disaster Risk Reduction 2030[7] and a National Strategy for Adaptation to Climate Change[8]. Furthermore, sectoral strategies on sustainable energy, energy efficiency, water resources and integrated solid waste management have been developed.

Egypt updated their first Nationally Determined Contribution (NDC) submission in July 2022. The updated NDC does not include an economy-wide emissions target but sets sectoral 2030 emission reduction targets for the electricity, oil & gas and the transport sectors. Egypt pledges

[5] In some countries, "Savanna fires" (incl. the prescribed burning of grassland) is accounted for in agricultural emissions under the burning biomass category instead of in the LULUCF sector. In this case, we followed national accounting standards based on UNFCCC reports to allocate the "Savanna fires" category under agriculture or LULUCF emissions. Savanna fires are reported under LULUCF for Australia, Brazil, New Zealand, and the United States, while they are reported under burning biomass for China and Indonesia. South Africa and Argentina report CO_2 emissions from savanna fires under LULUCF, but CH_4 and N_2O emissions under burning biomass. Since all emissions from Savanna fires in both countries are non-CO_2 gases, they are accounted for under "burning biomass."

[6] https://www.eeaa.gov.eg/Uploads/Topics/Files/20221206130720583.pdf.

[7] https://www.preventionweb.net/files/57333_egyptiannationalstrategyfordrrengli.pdf.

[8] https://faolex.fao.org/docs/pdf/egy141200.pdf.

to reduce GHG emissions from electricity generation, transmission and distribution by 33%, emissions from oil and gas use by 65% and from the transport sector by 7% compared to a 2030 business-as-usual scenario. To tackle emissions from industry, buildings, tourism and waste management, the NDC lists a number of specific mitigation measures (Government of Egypt 2022; CAT 2022). The sector-specific targets are, however, conditional on external financing support (ibid.) The agriculture and land use sectors are not included in mitigation actions in the NDC.

Egypt's updated NDC only includes a number of adaptation actions and measures for the agricultural sector that are focused on improved irrigation techniques, measures to preserve biodiversity, enhance the production efficiency of crops and livestock, improving animal feeds and health, adapting agricultural practices to new climate conditions and possibly expanding agricultural lands, building an effective system for crisis and disaster management for agricultural areas and supporting small-scale farmers in adapting to climate change. The Egyptian government also expressed interest to participate in international emission offset schemes (Government of Egypt 2022), first with a national, later with a regional market (Arab Republic of Egypt 2017).

Egypt's Sustainable Agricultural Development Strategy towards 2030 (SADS 2030), adopted in 2009, and Egypt's first Biennial Update Report (BUR), submitted in 2018, describe key objectives for the agricultural sector. These include enhancing water-use efficiency, expansion of reclaimed agricultural areas, enhancing agricultural productivity, protecting agricultural lands from soil degradation, increasing the competitiveness of agricultural products, raising the degree of food security, reducing rural poverty and enhancing the climate for agricultural investment. Enhancing the use of biomass as an energy resource, e.g. through anaerobic biomass digesters, is highlighted as a key mitigation activity in the agricultural sector that has been implemented from 2010 until 2015 in Egypt's first BUR. Additionally, the BUR lists a feed-in tariff for electricity generation from agricultural residues and biogas, reducing the cropland area used for rice cultivation, reducing livestock emissions through feed supplements, increasing milk productivity and improved breeding and producing compost and bioenergy from agricultural waste and manure from 2016 onwards as specific mitigation actions to be implemented in the agricultural sector (Ministry of Environment 2018).

The Egyptian Environmental Affairs Agency (EEAA) and the Climate Change Central Department generally spearhead the national climate change mitigation and adaptation strategies (Global Alliance for the Future of Food 2022). The Egyptian Environmental Affairs Agency (EEAA) is responsible for implementing environmental policies for which the Ministry of Environment (MoE) is in charge (Government of Egypt 2019). In general, the development focus of Egypt is on water and food security.

Egypt's Ministry of Agriculture and Land Reclamation (MALR) sets production targets (Global Alliance for the Future of Food 2022), including increasing total levels of production as well as self-sufficiency targets for specific crops such as wheat and maize (IFPRI 2018). The Ministry also defines agricultural policies including subsidies for agricultural inputs and crop-specific permits. In the past decade, policies were adopted which aim to shift domestic production to high-value and less water-intensive export crops while restricting the production of water-intensive crops that can be imported (IFPRI 2021). Particularly for rice, the government has set spatial boundaries where cultivation is allowed to limit associated water use (IFPRI 2018). The Ministry of Water Resources and Irrigation (MWRI), together with local water user associations (WUAs), governs Egypt's (irrigation) water resources (Fanack 2018). The Ministry of Social Solidarity is in charge of food subsidies including ration cards, bread subsidies and cash transfers (Ghoneim 2014).

The Egyptian government subsidises nitrogen fertilisers in two ways: directly, by distributing quotas of subsidised fertiliser to farmers and indirectly, by supplying subsidised natural gas to local fertiliser production companies (IFPRI 2020). Both fertiliser and natural gas prices were recently (Nov 2021) increased (by 50% and 28%, respectively), aiming to regulate (limit) exports and to reduce the overuse of nitrogen fertilisers (Arafat 2021; Enterprise 2022). Fertiliser producers are now required to provide at least 65% of their production to the domestic market of which 10% may be sold at market price and 55% of the indicated subsidised price (Reuters 2021).

1.5 Current developments and trends

Egypt's population is growing and therewith the demand for food. To meet rising food demand and in reaction to overpopulated land in the Nile Delta, more and more agricultural activities are shifted to reclaimed desert lands, also referred to as 'new lands' (Energypedia 2020). Land reclamation projects have faced significant challenges in the past, including high costs and limited water resources. For current plans to reclaim 630,000 ha of land, 80% of the water needed will be sourced from underground aquifers and 20% shall come from the Nile river. Drilling and maintaining irrigation wells involves significant energy demand and infrastructure costs though, putting the sustainability of these plans into question (USDA Foreign Agricultural Service 2016).

Another general trend is that many agricultural lands are being lost to urban infrastructure (Radwan et al. 2019) – an average of 3,108 ha per year in the Nile Delta (old lands) and 1,200 ha per year in the Greater Cairo area alone. Hereher (2012) reported that about 136 km^2 of agricultural land were lost due to urban sprawl between 1973 and 2006 in the Cairo area. The Egyptian government has started sanctioning illegal building activities (Reuters 2018; CropForLife 2022). Sea level rise is projected to lead to a huge loss of land in the Nile Delta, due to inundation and erosion, affecting local agricultural land as well as urban infrastructure (UNDP NAP-GSP 2018).

Concerning the use of fertilisers, Egypt's nitrogen fertiliser production has, on average, increased by 9% per year between 1961-2019 (FAO STAT 2021). Between 2009 and 2019, the increase in production amounted to 54%. Furthermore, the increasingly high cropping intensity leaves no time for recovery or fallows, thus having severe negative effects on the soil quality (EEAA 2016). More land in Egypt has become dedicated to livestock feed i.e. grain crops, complemented by imports of maize, barley and soybean (ibid).

Egypt's agriculture and thus food security almost fully depends on continued Nile water flows. Water saving measures and water efficiency (crop per drop) in agriculture are of the highest importance for Egypt (Luo et al. 2020; van Terwisscha Scheltinga et al.). In January 2022, President Abdel Fattah el Sisi called upon farmers to adopt modern irrigation systems, which would decrease fertiliser input needs by 40-60% (Enterprise 2022), addressing three challenges in Egyptian agriculture: fertiliser overapplication, limited water availability and the threat to water quality due to excess drainage water.

The Government of Egypt also aims to make its agricultural production more climate-smart and more digital: The Ministry of Agriculture and Communication aims to use mobile phones to assist farmers in determining the optimal planting, irrigation and harvesting dates as well as with pest and insect control (Egypt Today 2020). The International Fund for Agricultural Development (IFAD) and partners are developing a Dynamic Agriculture Information and Response System (DAIRS) to improve forecasting and coping with climate related hazards (IFAD

2015). The government together with a local mobile phone operator is also working on an app-controlled irrigation system which is coupled with soil moisture sensors (EcoMENA 2021).

Egypt has a relatively small but growing organic farming sector with about 2.8% of the country's total agricultural land being under organic management (ITC 2022; FiBL; IFOAM 2019). The SEKEM group has been pioneering in the organic sector in Egypt, operating organic farm lands, offering training and conducting research (IFOAM; FiBL 2006).

1.5.1 Diets and food waste

In Egypt, diets are changing with an increasing per capita consumption of meat, making livestock rearing a profitable and expanding business. Per capita consumption of beef and veal has increased by almost 60% and consumption of poultry meat by 164% between 1990 and 2019 (OECD 2023). Egypt's per capita food waste amounted to 91 kg per capita in 2021, marking an increase from 50 kg in 2018. Approx. 50% of vegetables and fruits, 40% of fish and 30% of milk and what are wasted each year in Egypt according to an FAO study (FAO 2019). Significant wastage is related to celebrations during religious holidays, weddings and family gatherings, as well as in restaurants and hotels. During the fasting month of Ramadan, food waste has been found to increase (Elmenofi et al. 2015). Also, losses occur during storage and due to poor postharvest handling. To tackle food waste, a draft law to establish incentives and fines in order to reduce food waste was developed in Egypt in 2022 (FAO 2019; Egypt Today 2022).

1.5.2 Recent developments in national context

Business and smallholder farmers suffered during the Covid-19 pandemic: input prices increased, food and feed supplies were limited, and marketing opportunities and overall income for many smallholders decreased due to the absence of traders and closure of some markets (Arcgis 2020).

Currently, Russia's invasion of Ukraine has severe impacts on Egypt's food, mainly wheat, imports (Financial Times 2022; IFPRI 2022). Egypt imports about 13 million tonnes of wheat annually corresponding to 62% of the total wheat consumed in Egypt of which, between 2018-2020, 45-72% were imported from Russia and 12-27% from Ukraine (IFPRI 2022), i.e. a significant share. In response to the Black Sea import disruptions, Egypt is currently diversifying its food import sources and temporarily banning the export of wheat and other staple crops (IFPRI 2022).

1.6 Vulnerability and adaptation

Climate change is projected to increase temperatures and decrease precipitation in Egypt (EC 2021). Egypt's agriculture is largely dependent on the Nile's water resources, while the Nile Delta is threatened by rising sea levels and the associated saltwater intrusion (Arab Republic of Egypt 2017; UNDP 2022). The Nile Delta is described as one of the World's three extreme vulnerability hotspots (UNDP NAP-GSP 2018), with climate change being projected to decrease crop productivity in Egypt until 2040 by 12% for wheat, 28% for vegetables, 47% for corn and by 26% for rice (Abd El Mowla and Abd El Aziz 2020). Agricultural production in the Nile Delta, the country's 'food basket' with the most fertile soils, is particularly vulnerable due to erosion, saltwater intrusion and flooding events (Global Alliance for the Future of Food 2022). The Global Alliance for the Future of Food estimates that, due to the impacts of climate change and the currently unsustainable irrigation practices, Egypt will suffer from water scarcity and a fall in grain productivity of 11% by 2025 (Global Alliance for the Future of Food 2022).

In terms of livestock production, current evidence shows that temperature increase leads to harmful heat stress, which negatively impacts livestock productivity. New animal diseases have emerged in Egypt, which have strong negative impacts on livestock production. These include bluetongue disease and rift valley fever, which are both attributed to significant changes in the Egyptian climate (Arab Republic of Egypt 2017).

Egypt's National Strategy for Adaptation to Climate Change and Disaster Risk Reduction puts a strong focus on the availability of water resources and improving water management in Egypt. For the agricultural sector, the strategy emphasises the need for increased productivity and water conservation. Additionally, it highlights the establishment of an effective institutional system for crisis and disaster management, measures to promote biodiversity, breeding and use of plants that are capable of adapting to changed climatic circumstances, increasing the content of soil organic matter and improving soil quality, increasing irrigation efficiency and using new irrigation techniques, improving animal health and feeds, measures to protect fish and providing support to small-scale farmers as key adaptation measures for the agricultural sector (Government of Egypt 2011).

Egypt's updated NDC lists similar adaptation actions and measures for the agricultural sector that are focused on the development of flexible agro-economic structures for more efficient land resource management. These include using modern surface irrigation techniques to increase the efficiency of agricultural water use, changing crop patterns, expanding the biodiversity of strategic crops and livestock varieties by introducing new traits tolerant to extreme weather events, and establishing an institutional system for crisis and disaster management for agricultural areas. The NDC further emphasises the need for capacity building and support for smallholder farmers in adapting to climate change (Government of Egypt 2022). For the implementation of the NDC measures, Egypt relies on technology transfer and financial flows from industrialised countries (Arab Republic of Egypt 2017). Adaptation at farm level requires knowledge transfer and possibly funding (loans, starting capital) to make necessary changes and investments into cleaner production.

2 Key areas with high mitigation potential

2.1 Introduction

In this section, we quantify the potential of three mitigation options and explore the co-benefits and barriers to their implementation in a country-specific context. In selecting which three mitigation options to quantify, the contribution of different emission sources was considered, along with the potential for socio-economic and environmental co-benefits, the country-specific context of the agricultural sector (see Section 1), and the general feasibility for implementation.

2.1.1 Selection of priority mitigation actions

As seen in Figure 4, the largest source of agricultural sector emissions is enteric fermentation from livestock followed by emissions from synthetic fertiliser, rice cultivation, and manure left on pasture.

For Egypt, we thus selected the following measures:

- Improved nutrient management
- Shifting to non-continuous irrigation for rice cultivation
- Decarbonising on-farm energy use.

Reducing and optimising the use of synthetic fertilisers would reduce overapplication of fertiliser and thus decrease N_2O emissions while delivering co-benefits for soil health and water use and quality. Shifting to non-continuous irrigation for rice cultivation would decrease CH_4 emissions as well as reduce irrigation needs and related energy consumption. Increasing the use of solar irrigation pumps and bioenergy from crop and livestock residues would decarbonise on-farm energy use and reduce emissions from burning crop residues and manure management. Enhancing water-use efficiency in irrigated agriculture and recycling agricultural waste and manure are also mentioned as key mitigation activities in Egypt's first Biennial Update Report to the UNFCCC (Government of Egypt 2019).

Any mitigation measure in the agricultural sector in Egypt must be considered in the context of national priorities to raising the degree of food security and self-sufficiency for essential food commodities and reducing poverty in rural areas (Government of Egypt 2019).

2.1.2 Overall mitigation potential

Based on estimates provided in the literature, the implementation of the three selected mitigation options could contribute to an overall emission reduction of 1–7 $MtCO_2e$/year in the agricultural sector and up to 7.6 $MtCO_2e$/year in the energy sector (as a result of using solar irrigation pumps and replacing demand for petroleum gas with bioenergy pellets). This leads to an overall potential in the range of 8–14.6 $MtCO_2e$/year, corresponding to 2–4% of Egypt's total GHG emissions in 2019 (see section 1.3).

However, there is some uncertainty in terms of overlaps between mitigation options. In order for Egypt to be compatible with the 1.5°C limit of the Paris Agreement, its conditional NDC target should reduce emissions by 25% until 2030 compared to current levels (CAT 2022). Thus, the mitigation measures outlined in the following sections should form a part of a broader set of measures that would be necessary to bring Egypt's agriculture sector on track to reaching long-term climate targets.

As part of such measures and in addition to the mitigation measures described in detail below, GHG emissions from intensive and semi-intensive cattle farms in Egypt can be reduced by reducing the emissions intensity of livestock through improved manure management and improving livestock health. Monitoring and improving the health and reproductive status of livestock can decrease the rate of disease and output loss, thus improving animal welfare, productivity and thereby decreasing the emissions intensity of production (Llonch et al. 2017).

Egypt's enteric fermentation emissions intensity per tonne of cattle meat is notably low compared to most high-producing developing countries (FAO 2022a; FAO 2022b). This is likely due to the structure of bovine production systems in Egypt, where beef cattle are primarily raised in intensive or semi-intensive systems, with the latter consisting of already-improved local breeds (FAO 2018). Current cattle mortality rates are also relatively low at 2% (Moharam 2022). The largest source of livestock emissions in Egypt is buffalo, which makes up almost half of enteric fermentation emissions. Beyond reducing beef cattle herd size, it is likely that most emission reductions from the livestock sector can be achieved through implementing good management practices related to feed optimisation and health in dairy cattle and buffalo systems.

Feeds are the main entry points to influence cattle digestion, enteric fermentation and ultimately also manure quality. Well-calculated diets optimise nutrition (avoiding surplus nutrients like nitrous (N) and phosphorus (P) to be excreted, see also (Interreg 2019)), increase N-use efficiency and decrease methane generation in the rumen (Tedeschi et al. 2021). Cattle manure management in stables could be improved by separating solids and liquids, reducing methane generation from both the cleaner liquid and the drier solid fractions (WRI 2019). Technical options range from simple gravity/grates/ponds that let solids settle to more thorough screw presses or centrifuges as well as chemical flocculants. The Egyptian Environmental Affairs Agency, as part of the Ministry of Environment, defined legal requirements for manure management of industrial cattle production: stables should evince a slight (1%) slope, so most urine would run-off into open canals along the stable (Nasereddin 2022). The separation of dry and wet manure fractions helps segregate nutrients, allowing a more targeted nutrient addition to different farmer fields. Cattle manure could also be used for bioenergy generation (see section 2.2.3) (FAO 2017b).

Feasible mitigation strategies for dairy cows in Egypt, evaluated by Khalifa and El-Sysy (2017) include improved animal productivity, forage processing, rotational grazing, changes in forage species and maturity, and the use of high-quality forages. These mitigation options, without accounting for overlap between them, can potentially reduce methane emissions by 9–40% (ibid). The production potential and reproductive performance of dairy buffalo is also quite low, and can be improved through capacity building, optimising feed intake, improved health care, and appropriate milking routines (Arefaine and Kashwa 2015). It is unclear to what extent these mitigation practices can be applied to buffalo meat.

Improved manure management and livestock health improvements comes at high costs though. Farmers likely do not have the capacity to invest in the suggested changes and might not see sufficient return on investment to consider the additional expense and effort as worthwhile implementing unless consumers or the government were willing to pay for it. To ensure large-scale adoption, measures would have to be incentivised or controlled. Educational campaigns and extension services may further help and foster farmers willingness to pay. Additionally, capacity building is needed, so that farmers understand the urgency, the positive impact and how to implement the improved practices, particularly regarding manure management. In (extensive) smallholder farm systems, the traditional roles of men (feeds, care) and women (vaccinations, milking, processing and marketing) may have to be considered in educational campaigns (FAO 1994).

Emission reductions in the production process of synthetic fertilisers may be achieved by shifting towards the production of green ammonia (by using low carbon hydrogen), thus increasing the energy efficiency. Currently, ammonia (NH_3) is mostly produced using methane in the so-called steam methane reforming (SMR) process, which accounts for 90% of the CO_2 generated in ammonia production. In Egypt, for at least one of nine large factories producing nitrogen fertiliser (the Kima plant in Aswan), the government plans to shift towards the production of green ammonia (The Royal Society 2020). While not pertaining to agricultural sector emissions, shifting from brown ammonia (with fossil fuels as feedstock without carbon capture and storage) to green ammonia, could save about 1.6 tonnes of CO_2 emissions per tonne of NH_3 produced (The Royal Society 2020). Egypt produces 3.7 million tonnes of ammonia per year (Galal 2021), translating into potential savings of 6 million tonnes of CO_2 emission reductions from the energy sector.

Furthermore, demand-side options like shifting from N-intensive diets (Hayashi et al. 2018) and reducing food waste (Shibata et al. 2017) can also considerably reduce GHG emissions in Egypt. Reducing the overall demand for meat and milk in Egypt would reduce herd sizes and thus emissions from manure and enteric fermentation. Suggesting a reduction in meat consumption will not affect the national goal of greater food security for large parts of the population, and meat alternatives or pulses could and, in fact, always did complement local traditional dishes, constituting a healthier diet with a lower GHG and water footprint. Reducing food waste through targeted purchases and better storage will improve food security and save water while reducing emissions from the production of wasted food and waste management.

No literature that estimates the full mitigation potential of agricultural emissions in Egypt was found.

2.2 Prioritised mitigation options

2.2.1 Improved nutrient management

Measure

GHG emissions may be mitigated from reducing and optimising the application of synthetic fertiliser. In fertiliser application, N-emissions could be decreased by reducing the overapplication of fertiliser, by setting a focus on optimal nutrient absorption by the plants or by optimising the type of fertiliser (compounds/compost instead).[9]

Policies encouraging/rewarding efficiency increases in N uptake would be well suited to achieve yield gains and reduce nitrous oxide emissions. Efficiency increases could be achieved by coating fertiliser pearls, e.g. with neem like in India, a shift of fertiliser subsidies to support higher NUE rather than total fertiliser input (WRI 2019) and better timing of on-farm fertiliser application reduces fertiliser requirements (emission savings from production) as well as emissions through N-volatilisation (Robertson and Vitousek 2009).

Status

While fertiliser use has decreased over the past decades (see section 1.5 and Government of Egypt 2019), related emissions are still high. In Egypt, urea is the major nitrogen source, but its application with low or no phosphorus or

[9] Concerning the optimal nutrient provision to maximise yields, the International Fertiliser Institute refers to the so called "Four R's": fertilisers need to come from the right source, be applied at the right rate, at the right time and the right place (roots, surface, leaves) (WRI 2019).

potassium (Hafez et al. 2012) and low N recovery rates (7-32%) in Egyptian sandy soils (Abd El-Latif et al. 1984), leaves a gap between nitrogen applied and nitrogen actually consumed by crops, leading to N-losses through volatilisation (NH_3) from surface-applied urea. (Elrys et al. 2019) report that NH_3 losses due to emissions have increased, being the main contributor to gaseous nitrous oxide emissions (83%) in Egypt. Furthermore, the high cropping intensity leaves no time for recovery, with severe negative effects on the soil quality (EEAA 2016). Increasing land areas in Egypt became dedicated to livestock feed while the increasing livestock production has led to 'dumping' of animal manure, with little consideration of actual uptake capacity and nutrient needs of crops at the chosen point in time (WRI 2019).

Potential	Roe et al. (2021) indicate a technical mitigation potential of nutrient management for Egypt between 0.4–5 $MtCO_2e$/year based on other studies, corresponding to 6–63% of emissions from synthetic fertiliser application in 2019 (based on FAO data). The range of the potential is due to different assumptions of the underlying studies on the amount of cropland on which the mitigation measure can be implemented and whether it overlaps with other nutrient management mitigation options are accounted for.
Co-benefits	A higher NUE does not only lead to lower direct agricultural emissions, but also to a lower demand and possibly lower production of fertilisers in Egypt. Using compost improves the soil fertility and increases the buffer capacity, so (10%) less irrigation water is needed and it reduces pathogens (Louis Bolk Institut 2010). Lower irrigation water needs also translate into lower fuel and electricity needs for irrigation (ibid). Additionally, negative water impacts like freshwater acidification and groundwater contamination can be mitigated if fertiliser use is reduced (Vries et al. 2013). Reducing fertiliser use can also contribute to soil health and protecting biodiversity by avoiding changes in soil pH and soils toxicity (Bobbink et al. 2010).
Barriers	**Economical barriers**: To avoid a loss of income from yield decreases, farmers may tend to over-apply fertiliser as a protective measure. Investments into cleaner production processes come at an initial cost. Loans or governmental grants for climate-smart industrial investments may foster their implementation. Lower operating costs should be able to offset the initial investment costs. Additionally, for as long as Egypt is exporting fertilisers (see section 1.3), a reduction in national fertiliser application does not necessarily lead to lower amounts of fertiliser produced. **Technical barriers:** Farmers in Egypt lack knowledge on soil conditions and plant nutrient needs, leading to imbalanced fertilisation (ERF 2016). Most farmers believe that the more fertiliser the better the growth, leading to inefficient N utilisation (ibid). From many sides, the focus seems to be on quantity, "the more the better," rather than on the optimal provision of nutrients to the plants. With irrigation water, the focus seems to be "the more the better," with too much water flushing away soil nutrients and the fertiliser, reinforcing over-fertilisation. **Policy barriers:** Subsidising nitrogen fertilisers counteracts the reduction of synthetic fertilisers in Egypt (IFPRI 2020, see also section 1.5).

2.2.2 Shifting to non-continuous irrigation for rice cultivation

Measure

The main source of GHG emissions in rice cultivation is methane (Farag et al. 2013). Methane is generated by anaerobic bacteria, so more aerobic (dry) conditions will reduce bacterial activities and thus methane emissions. Water requirements and GHG emissions in rice cultivation may be reduced without compromising rice yields by alternate wetting and drying (AWD) and mid-season drainage (MSD) (Livsey et al. 2019).

Other measures for further GHG emission reductions from rice cultivation in Egypt can include: an improved variety selection, a reduction in synthetic fertiliser application, the replacement of synthetic with organic fertilisers, the decrease of deep ploughing and stopping residue (rice straw) burning, using the straw as bedding for livestock, as livestock feed or for bioenergy generation instead (Farag et al. 2013; Hasan 2019; Elbasiouny and Elbehiry 2020; WRI 2019).

Status:

In Egypt, rice is commonly cultivated in the summer and under continuous flooding with about 5cm depth of standing water during the growing season (Elbasiouny and Elbehiry 2020). The Directorate of Agriculture of the New Valley Governorate of Egypt recently (June 2021) announced a successful first pilot for dry rice cultivation in the governorate (Egypt Independent 2021).

United States Department of Agriculture (USDA) indicated that rice is currently (2021) cultivated on up to 760,000 hectares of land, of which only a maximum of 451,000 hectares (i.e. 60%) were approved for rice cultivation by the government (World Grain 2021). The government of Egypt has recently (May 2021) passed a law to curb the illegal rice cultivation, to improve water usage and to preserve water resources, thus the total area of rice cultivation is projected to slightly decrease i.e., range only slightly above the maximal areal shares set by the government (World Grain 2021).

Potential

Roe et al. (2021) indicate a technical mitigation potential of improved rice cultivation practices for Egypt between 0.7–2 MtCO_2e/year based on other studies, corresponding to 10–39% of rice cultivation emissions in 2019 (based on FAO data). The range of the potential is due to different assumptions and methodologies of the underlying studies.

Co-benefits

Rice cultivation in Egypt is water intensive. Approx. 20% of agricultural irrigation water in Egypt is consumed in rice production (Elghafour 2016). Shifting to non-continuous flooding of rice fields not only reduces emissions but saves precious water resources. According to (IRRI 2009), alternate wetting and drying (AWD) systems need up to a quarter less water without causing a decrease in yields. For Egypt, assuming 9 billion cubic meters of irrigation water are used rice per year (Egypt Today 2018), 2.25 billion cubic meters of water could be saved annually (4% of Egypt annual Nile water share) without any changes in cultivation areas or production levels. IRRI (2009) reports from the Philippines that through a shift from continuous flooding to AWD farmers reduced the running times for their pumps by more than half and resulted in labour savings of 20-25%, implying higher profits for rice farmers.

Studying the actual water need of the rice plants at different growth stages and determining the optimal irrigation water demand for rice in Egypt will help to reduce the amounts of irrigation water supplied without affecting the yields.

Barriers

Biophysical/environmental barriers: Many land areas in the Nile Delta have low permeable soils, were historically naturally flooded for longer time periods by the Nile and have saline, shallow groundwater trough subsurface intrusion of seawater from the Mediterranean (Elbasiouny and Elbehiry 2020). Rice is grown on salty soils as a reclamation crop, i.e. to leach and lower the salt content of the soil (Elmoghazy and Elshenawy 2018). Building-in dry periods in rice cultivation will require a change not just in flooding regimes but also in drainage and in managing soil salinity.

Economical barriers: Changes in drainage systems and field management imply training needs for local farmers and additional labour costs for more fine-tuned irrigation and drainage. Yield increases or cost savings, e.g. through less demand for diesel fuel, could be an incentive for implementation. While Egypt used to subsidise irrigation water, nowadays, Egyptian farmers do not pay for water and merely bear the on-farm irrigation costs (Abas Saleh 2018) (see section 2.2.3).

Socio-cultural/technical barriers: Current national recommendations for good practices in rice cultivation still include permanent flooding for large parts of the crop growth stages (Elmoghazy and Elshenawy 2018). For as long as extension advice focuses on continuous flooding, it is unlikely to see Egyptian farmers shift to non-continuous flooding. While research (Jiang et al. 2019; Linquist et al. 2015; Zou et al. 2005) agrees that non-continuous flooding reduces the global warming potential of rice cultivation, dry rice cultivation in Egypt is in the pilot stage and far from adopted at scale.

2.2.3 Decarbonise on-farm energy use

Measure

The two main technical options for lower and more sustainable on-farm energy use in Egyptian agriculture are solar irrigation pumps and bioenergy from crops and livestock residues (BEFs) (FAO 2017b).

Solar irrigation pumps require an upfront investment but save costs in operation and emissions (Energypedia 2020). According to RCREEE (2016), Egypt has an annual diesel fuel consumption from irrigation pumping in agriculture of about 3.7 million tonnes. The potential for GHG emission reductions when replacing diesel with solar irrigation pumps is substantial. Different pumps (with different capacities and ease of use) could serve different farmer market segments.

Secondly, by replacing residue burning[10] and unmanaged manure with a targeted renewable energy production for on-farm use, bioenergy can be generated from crops and livestock residues (FAO 2017b).

Status

In Egypt, about 40 billion cubic meters per of irrigation water per year are pumped to farmer fields (Ayyad et al. 2019). According to (El-Gafy and El-Bably 2016), pumping one cubic metre of water for crop irrigation in three different case study sites in Egypt with improved and non-improved diesel generated on average 0.87-1.11 kg of CO_2 emissions.

[10] In Egypt, most residues are burnt on the fields or in inefficient burners to quickly prepare the soil for the next cultivation cycle (FAO 2017b).

Naturally, residues are differently distributed across the country, varying not just in amounts but also in residue types and seasonally. The Middle Nile Delta region seems to be the most promising area for BEFs implementation as far as total residue availability is concerned, with the governorates of Behra, Sharkiya, Dakahlia and Kafr-El Sheikh being most suitable for pilots (FAO 2017b).

Potential

If on-farm energy use was to be completely decarbonised through measures such as solar irrigation pumps, it would result in emission reduction of at least 4 $MtCO_2e$/year according to our calculations – Egypt's on-farm energy use emissions in 2019 (see section 1.3). Egypt, like many developing countries, still faces challenges with capacity building in estimating and reporting GHG emissions. It is unclear to what extent on-farm energy use emissions are accurately reported; as a result, the mitigation potential can be even higher than our estimate.

Concerning bioenergy from residues (BEFs), FAO (2017b) analysed the national BEFs[11] potential and estimated that the maximum potential electricity generation potential with combined heat and power (CHP) technologies would be about 770 MW, able to supply 2.2. million households and avoiding emissions of 2.9 $MtCO_2e$/year. The biogas generation capacities are highest along the Nile where most industries are settled, too. Bioenergy may also take the form of briquettes and pellets: crop residues (prunings from citrus, olives, palm dates and other plants) are the most promising feedstock for these. If the suitable and available biomass was converted to briquettes or pellets, a combined total energy output of 1.878 kilo tonnes per year could be achieved. 31% of the LPG (Liquified Petroleum Gas) consumption (6,115 kt/year) could be replaced by briquettes and pellets from crop residues, supplying over 1.6 million households and avoiding emissions of 3.6 $MtCO_2e$/year (ibid).[12] When estimating the potential for BEFs it is important to recognise that not all residues are available for bioenergy production: some crop residues are used as livestock feed or in construction (ingredient for mud bricks). Furthermore, crop and animal residues/manure are also used as mulch (see section 2.2.1), helping to conserve soil moisture and to improve soil fertility though (FAO 2017b).

Co-benefits

Diesel fuel causes GHG emissions as well as diesel spills into the soil. Additionally, diesel fuel is increasingly expensive and difficult to access, particularly for lands in remote desert locations (Energypedia 2020). Costs were calculated and compared for a remote Egyptian desert farm in Bahareyia: 1 kilowatt hour (kWh) generated from diesel vs. from photovoltaic cost 1.3 vs. 0.95 Egyptian Pounds (LE) respectively, implying irrigation water costs of 0.35 LE and 0.19 LE per cubic meter of water respectively (ibid). Replacing diesel with renewable energy sources would thus reduce GHG emissions, pollution of the soil as well as save significant amounts of costs for farmers.

Barriers

Economical barriers: Smallholder farmers cannot afford the capital costs for purchasing solar irrigation systems, even though they are aware of the mid-to-long term money savings (Morshedy 2022). For the time being, only large-scale

[11] Residue types considered were straw (wheat, rice, broad bean, barley, flax, lentil), stalks (maize, cotton, sorghum, sesame, sunflower), prunings (citrus/orange, palm dates, grapes, olives), haulms (sugar beet, peanuts, soybeans), bargasse (sugar cane) and manure (chicken and cattle). Sheep and goat manure cannot be collected, except at a very small scale (FAO 2017b).

[12] However, there might be overlap between the potentials of using bioenergy for electricity generation and for briquettes or pellets since both options rely on the availability of biomass.

farms with modern irrigation systems can afford the capital costs (ibid). Implementing photovoltaic (PV) irrigation systems is strictly related to modern micro and sprinkler irrigation systems (ibid).

Technical barriers: When calculating the emission savings of solar powered pumps, the carbon footprint of the system production, delivery, maintenance and operation have to be compared to that of diesel pumps. There must also be a national recollection, repair and recycling system in place for damaged or worn-out parts. Additionally, a lack of awareness about how to use alternative sources of energy has obstructing the decarbonisation of on-farm energy use in Egypt (Energypedia 2020).

Policy/legal barriers: Despite the considerable GHG mitigation potential, according to our knowledge there currently are no national plans or targets for bioenergy development and use (FAO 2017b).

3 Barriers to implementing mitigation potential

In this section, we examine the main barriers to mitigation of agricultural emissions identified for the country, building on the findings of a report on general barriers prepared for this research project (Siemons et al. 2023) and the country-specific circumstances described in Section 1 of this report. The analysis of barriers below follows the clustering proposed in Siemons et al. (2023), according to the relevant governance level for taking action, while taking into account the classification from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land (Smith et al. 2019) within each of the governance levels.

3.1 Farm level

The mitigation options discussed in this report require upfront investments in infrastructure, machinery, and equipment, as well as capacity building to transition from current practices to alternative, more sustainable ones (e.g. cost of implementing separation systems for improved manure management). These potentially high costs, if not mitigated by the government, will represent a significant barrier for implementation.

Most Egyptian farmers, especially smallholders, lack the investment capacity, resources, and financial assistance needed to adopt new technologies or sustainable practices (economical/ technical barriers). There are usually significant upfront costs to adopting new technologies, and farmers may lack the knowledge on potential gains from sustainable practices or new technologies (Morshedy 2022; ERF 2016). Likely, a large number of farmers also lack education and awareness of the urgency for and how to implement mitigation measures.

Reducing GHG emissions is currently not a priority for Egyptian farmers when compared to other goals such as profitability (for farm businesses) or food security (for extensive, smallholder farmers). Considering Egyptian average income levels, GHG mitigation strategies have to be coupled with existing strategies towards greater water and food security while improving the livelihoods (nutrition, health, economic opportunities) of the Egyptian population (Government of Egypt 2019).

3.2 National level

A lack of strategic vision and commitment to quantifiable emission reduction targets for the agricultural sector in Egypt's updated NDC constitutes an institutional and political barrier towards better understanding and defining concrete adaptation and mitigation strategies for Egypt's food systems (Government of Egypt 2022). Through financing and investment policies, the Egyptian government aims to expand agricultural areas (e.g. through tax free land reclamation) and supports a greater mechanisation of farms (AUC Knowledge Fountain 2020), implying increasing GHG emissions.

Saving water and improving national food security are predominant national goals, i.e. the focus is on adaptation rather than mitigation, unless foreign investments or funds allow a stronger focus on emission reductions. At the same time, the Egyptian government invests, with direct financial support and marketing, into the export of agricultural commodities (AUC Knowledge Fountain 2020), that consume precious water resources, do not directly improve the national food security and cause GHG emissions – a calculated trade-off that provides important income to the government in order to sustain, amongst others, agricultural and food subsidies.

A significant economic barrier is the lack of funds for further data collection, training farmers and businesses, or support to develop effective policies and scaling up through assisting change at farm level (Arab Republic of Egypt 2017; UNDP NAP-GSP 2018).

Furthermore, a lack of impact monitoring, quality assurance and the risk of theft for equipment provided/supported act as barriers at the national level (Energypedia 2020). The scattered nature of information on the agricultural sector and GHG saving potentials (partially addressed in this report), further result in a lack of knowledge among policy makers (Arab Republic of Egypt 2017) that would enable sound decision-making in terms of effective policy development, decision-support to farmers and across agencies (economic, technical and social barrier).

3.3 International level

An economic barrier from international policies and trade are the fluctuating prices for imported and exported goods, that may increase expenses (e.g. for food imports) and decrease revenues (e.g. for agricultural commodities) for the Egyptian government as well as private investors, reinforcing the focus on basic and immediate needs and economic benefits.

Economic and policy barriers also emerge through unsustainable demand and trade patterns from abroad (Häberli 2018), e.g. not setting minimum environmental and social production standards or wasting food or fertiliser imported from abroad, which burdens national food and water security, causes unnecessary GHG emissions and hampers the Egyptian transition towards more sustainable agricultural production systems.

3.4 Consumer level

Changing diets towards higher levels of meat consumption run counter to a reduction livestock numbers and emissions from enteric fermentation in Egypt. Additionally, significant levels of food waste are related to celebrations during religious holidays, weddings and family gatherings and in restaurants and hotels (see section 1.5). Such cultural traditions and social habits pose barriers to reducing demand for animal products and food waste.

4 Recommendations

In a world compatible with the Paris Agreement, the agricultural sector will need to meet the growing food demand of people and animals, while contributing to other equally relevant climate and development objectives and adapt to a changing climate. Mitigation action in Egypt, one of the large emitters globally, is essential for limiting global temperature increase, including in the agricultural sector. The mitigation of climate change is also essential to Egyptian agriculture, where soil erosion, saltwater intrusion and flooding events in the Nile Delta have become a frequent, acute threat to food supply. The productivity of the land in Egypt is already threatened by climate change (see section 1.6), and measures to improve soil quality can increase the resilience of the agricultural sector, additionally to reducing GHG emissions.

This study identified and quantified three actions to reduce emissions associated with agriculture in Egypt that would improve productivity and provide environmental and economic co-benefits: reducing and optimising the use of synthetic fertiliser, shifting to non-continuous rice irrigation and decarbonising on-farm energy use.

Based on estimates provided by literature, optimising the use of synthetic fertiliser can reduce emissions by 0.4–5 $MtCO_2e$/year, corresponding to 6–63% of emissions from synthetic fertiliser application in 2019. An additional emission reduction of 0.7–2 $MtCO_2e$/year could be achieved by improved rice cultivation practices. Decarbonising on-farm energy use through measures such as solar irrigation pumps and replacing demand for petroleum gas with bioenergy pellets could lead to further emission reductions in the energy sector of up to 7.6 $MtCO_2e$/year. Additional emission reductions related to the agricultural sector could be achieved through improved manure management, improving livestock health, optimising livestock feed, decarbonising the production of synthetic fertiliser and promoting measures on the demand side to reduce meat consumption and food waste.

Many of the suggested measures have co-benefits that are already an integral part of Egypt's national policy goals, such as an improved water and food security. Additionally, the suggested measures can play an important role in improving soil health and reduce irrigation needs, which is urgently needed to supply the population with food and guarantee production for export.

However, the successful implementation of agricultural mitigation measures is hampered by numerous barriers on the farm, national, international, and consumer levels. These include a lack of investment capacity and knowledge of farmers, a lack of emission reduction targets for the agricultural sector and counteracting policies promoting the export of agricultural commodities and subsidising synthetic fertiliser. Additionally, the national focus is on improving national water and food security, potentially putting GHG emission reductions in the background.

To accelerate the uptake and implementation of the measures described in this report, it is key to enhance the national mitigation framework in the agricultural sector and reconcile agricultural and development goals and mitigation options, while strengthening the international competitiveness of the sector and protecting it from environmental and economic risks. Some concrete options are outlined in the following paragraphs:

1. Enhancing the national climate mitigation framework in agriculture

Emission mitigation targets or measures from the agriculture and land use sectors are currently not included in Egypt's NDC. While Egypt's Ministry of Agriculture and Land Reclamation sets production targets and defines agricultural policies including subsidies, no comprehensive strategy for the agricultural sector could be found that includes approaches to mitigate GHG emissions. Setting targets and referring to concrete mitigation potentials will also make international donors more likely to provide financial and institutional support for implementing mitigation measures.

2. Align overall agriculture framework with climate mitigation objectives

Key policy objectives of the Egyptian government are to improve food and water security. The mitigation measures discussed in this report can contribute to these objectives and should be promoted through an agricultural policy framework that aligns both climate and development targets.

3. Selected ideas for how mitigation could be strengthened

Targeted supportive policies would be needed that set incentives for low carbon on-farm energy use, high nitrogen use efficiency, water and pumping savings, regulating and encouraging good manure management and rewarding non-continuous rice flooding/irrigation. For example, farmers could be paid to use less water or farmers could be supported in trading irrigation water to use water resources most efficiently (IFPRI 2021). Agricultural taxes should be revised to be based on the area under cultivation, cropping patters and the applied irrigation methods with exemptions to farmers that apply sustainable practices (Arab Republic of Egypt 2009). Furthermore, the Egyptian government may increase the demand for climate-and-water smart agricultural products through a more sustainable public procurement (ICLEI 2017) in accordance with Egypt's National Action Plan for Sustainable Consumption and Production (CEDARE 2017).

The large-scale implementation of solar power irrigation systems must be accompanied by a sound plan for equipment repair, re-collection and waste management once the equipment reaches its end-of-life. Many new jobs could be created in the solar industry. High-level educational exchanges are already ongoing, e.g. there is a German-Arab Master Programme in 'Renewable Energy and Energy Efficiency for the Middle East and North Africa Region' (REMENA) between the University of Kassel and Cairo University, which has been operational since 2009.[13]

Training and financial support are necessary to provide farmers with the equipment and knowledge to implement mitigation measures. Particularly, microfinance, access to technology, as well as maintenance and repair services or trainings would help to increase the spread of solar irrigation pumps. Small-scale solar-powered irrigation stations would help encourage small-holder farmers to adopt this technology in their traditional surface irrigation (Morshedy 2022).

While this report focuses on improvements on climate-friendly agricultural production, it is essential to highlight that without changes to dietary patterns mainly in developed countries, a sustainable and just 1.5°C pathway is not feasible. Discussing alternative narratives next to the current agricultural expansion plans could help understand the implications of a shift to largely plant-based diets and potentially avoid disruptions in the sector in the medium to long term. International research reports that demand-side measures, such as shifting to less meat intensive diets and reducing food waste, have a high mitigation potential while contributing to other co-benefits at relatively lower costs (Roe et al. 2021). In Egypt, enhancing plant-based diets and reducing food waste could considerably reduce GHG emissions (see section 2.1.2). Suggesting a reduction in meat consumption would not affect the national goal of greater food security for large parts of the population, and meat alternatives or pulses could and, in fact, always did complement local traditional dishes, constituting a healthier diet with a lower GHG

[13] https://www.uni-kassel.de/eecs/en/remena/home.

and water footprint. Reducing food waste through targeted purchases and better storage also contributes to improving food security and saving water while reducing emissions from the production of wasted food and waste management.

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