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Pathways towards a Green Economy in Egypt

Analyzing decarbonization and resource efficiency pathways along value chains to support green private sector development in Egypt

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List of Abbreviations, Units and Symbols

AR	Augmented Reality
CO2e	Carbon Dioxide Equivalent
COP	Coefficient of Performance
CMC	Carboxymethylcellulose
CREA	Council for Agricultural Research and Economics of Italy
EEAA	Egyptian Environmental Affairs Agency
EI – C	Expert interview cotton value chain
EI - R	Expert interview refrigerator value chain
EI - S	Expert interview sugar beet value chain
EFI	European Forest Institute
EOL	End of Life
FGD - C	Focus group discussion cotton value chain
FGD - R	Focus group discussion refrigerator value chain
FGD - S	Focus group discussion sugar beet value chain
GCI	Green Cooling Initiative
GDP	Gross Domestic Product
GEI	Green Energy Initiative
GHG	Greenhouse Gas
GMO	Genetically Modified Organism
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
HIPS	High Impact Polystyrene
KPI	Key Performance Index
LCA	Life Cycle Assessment
LEDS	Low Emission Development Strategy
MCA	Multi Criteria Analysis
MENA	Middle East and North Africa
MSMEs	Micro, Small and Medium Enterprises
NCCC	National Council for Climate Change
ODP	Ozone depletion potential
RAC	Refrigeration and Air-Conditioning
RECP	Resource Efficiency and Cleaner Production Program
SDG	Sustainable Development Goal
SMEs	Small and Medium-Sized Enterprises
SOM	Soil Organic Matter
T&A	Textile and Apparel
UNEP	United Nations Environment Program

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1 Introduction

Egypt's economy is the largest in North Africa and faces a number of challenges, including increased vulnerability to climate change, resource depletion, rising poverty and unemployment. Vulnerability to climate change, coupled with dependence on natural resources such as water from the Nile, can exacerbate the impact of natural disasters such as storms, floods and droughts, adding to their significant socio-economic impacts (Harris et al., 2020; IMF, 2022). These issues reflect broader concerns prevalent in the MENA region, including factors such as insufficient food and water resources, limited adaptive capacity and rapid urbanization that make the region highly vulnerable to climate change (Namdar et al., 2021; Waha et al., 2017).

Egypt is facing a critical water shortage due to limited resources, fluctuating availability of freshwater for irrigation, and competing demands for water (Khadr et al., 2017). Non-integrated water management and continued population growth exacerbate this problem (Elsaie et al., 2023). Given Egypt's heavy reliance on the agricultural sector, this scarcity poses a significant threat to food security and the overall economy (EEAA, 2010). However, addressing water scarcity and food security alone is not sufficient to provide a comprehensive picture of the challenges faced: Issues such as waste management also require urgent attention to prevent further environmental degradation and health hazards. Proper waste management strategies are critical to maintaining ecological balance and public health, yet they remain an under-prioritised issue on the current national agenda (Milik, 2021). In addition, the promotion of economic development, especially for small and medium-sized enterprises (SMEs), is essential. SMEs, which are key drivers of innovation and employment, face numerous obstacles in Egypt, including limited access to finance, bureaucratic hurdles and a lack of market opportunities. Addressing these challenges is paramount to reducing unemployment and increasing economic resilience (Zamzam, 2017). To address these challenges, the concept of the green economy, and in particular the greening of value chains, offers a promising starting point. Egypt has already taken the first steps towards developing a national green economy strategy and has implemented projects, for example in the field of renewable energy.

In light of Egypt's transition to a green economy, this report focuses on reducing greenhouse gas (GHG) emissions and increasing resource efficiency along three different value chains in which SMEs play a crucial role. In order to support SMEs in Egypt to take advantage of implementing greening options along value chains, more detailed analyses are needed. Therefore, the aim of this study is to analyse three selected supply chains to identify greening opportunities for SMEs. Against this background, the project report is structured as follows: Chapter 2 introduces the background with an overview over the concept of green economy followed by Egypt's economy and its green economy. This is followed by a presentation of the value chains and an overview of the respective sectors. Chapter 3 describes the research approach, methods and data collection. The following chapters examine the three selected value chains *cotton, sugar* beet and *refrigerators*, including environmental hot spots, greening options as well as the experts' evaluation of those greening options. The report concludes with key recommendations in Chapter 7.

2 Background

2.1. Green economy concept

The concept of a green economy is based on the idea of creating a positive link between nature and the economy. A green economy is embedded in the overarching principles of sustainable development (Zhironkin & Cehlár, 2022) and is defined by the United Nations Environment Program (UNEP) as an economy that is sustainable, has low carbon emissions, uses resources efficiently, and is socially inclusive (UNEP, 2011, 2018).

The term was introduced by David Pearce and Edward Barbier in 1989 in the Blueprint for a Green Economy series and is based on the recognition of the undervalue of ecological and social costs in the economic system (Loiseau et al., 2016; Pearce et al., 1992). From there, it took until the 2012 Rio+20 Summit[1] for the concept to become an international guiding principle for sustainable development (BMUV, n.d.; UN, 2012). The principle was based on the Green Economy Initiative (GEI) which was launched by UNEP in 2008. The aim of the initiative was to align economic policy decisions with the environment and to encourage policymakers to channel investments into a green economy (UNEP, 2017b). In other words, to make green investments, which refer, for example, to investments in renewable energies, water supply, environmentally friendly transport or sustainable production (The Green Economy Coalition, 2023). The GEI was then further developed into the Inclusive Green Economy approach, which is a strategic approach to achieving sustainable development (UNEP, 2017b). It describes an economy that is "low carbon, efficient and clean in production, but also inclusive in consumption and outcomes, based on sharing, circularity, collaboration, solidarity, resilience, opportunity, and interdependence" (ibid.). Currently, there is no universal definition of a green economy, but the most common understanding is based on the core of the Inclusive Green Economy approach: "An inclusive green economy is one that improves human well-being and builds social equity while reducing environmental risks and scarcities" (UNEP, 2017a).

Karl Burkart defines a green economy based on six sectors: renewable energy, green building, eco-friendly transport, water resources management, waste management and land management (Burkart, 2012). Renewable energy is derived from natural sources like sunlight, wind, water, geothermal heat, and waves. It is essential to note that the infrastructure and components used to generate renewable energy have limited lifespans and potential environmental impacts. Green building encompasses environmentally responsible and resource-efficient construction practices from planning to demolition. The assessment of the suitability of demolished building materials for reuse is crucial. Eco-friendly transportation covers sustainable transport modes and infrastructure with a focus on social, environmental, and climate considerations. Water resources management involves planning and optimizing water usage. As water becomes scarcer, balancing human needs with environmental sustainability is critical. Waste management includes processes from waste generation

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[1] UN Conference on Sustainable Development in Rio de Janeiro in June 2012 (BMUV, n.d.).

to disposal. With rising consumption, it is challenging for ecosystems to neutralize waste faster than it accumulates. Land management deals with the use and development of land resources, impacting agriculture, reforestation, water resources, and ecotourism. Both, the positive and negative effects on ecosystems need to be considered (Lisitsa et al., 2022).

Various notions of a green economy are prevalent, ranging from weak to strong sustainability. The pace and scope of changes needed to adopt green economy strategies can vary significantly, depending on the chosen approach. Some solutions align closely with the conventional economy, necessitating only minor adjustments, for instance, adopting cleaner production methods to enhance eco-efficient manufacturing. Conversely, other solutions mandate substantial transformations in both production and consumption patterns. Examples include industrial ecology or nature-based solutions, which demand substantial investments in green infrastructure (Loiseau et al., 2016). Today the term 'green economy' evolved into a framework for a paradigm shift to decouple environmental degradation and the economy. It is considered as a pathway toward sustainable, inclusive economies that are in harmony with environmental and social targets.

This study focuses on a green economy perspective based on the doughnut economy approach. The basic idea behind this economic concept by the British economist Kate Raworth is to draw a "doughnut" that represents the ecological limits of the planet on the outer periphery for fulfilling basic social needs of people on the inner periphery. In the outer layer of the donut, ecological aspects such as the protection of biodiversity, climate change and resource utilization are taken into account to ensure that the environment is managed sustainably and that planetary boundaries are not exceeded. In the inner layer of the donut, social aspects such as food security, education, healthcare and social justice are taken into account. The donut economy promotes an approach where economic activity takes place in an environmentally safe and socially just place that lies between planetary and social boundaries (Ross, 2019).

The Sustainable Development Goals (SDGs) serve as an internationally adopted set of goals for integrating environmental protection and sustainable economic development. In the present context, certain SDGs may be relevant, including particularly SDG 12 with sustainable consumption and production as a key target. In order to reduce greenhouse gas emissions and adapt to climate change, SDG 13 may be pertinent as well. However, SDG 7, which includes affordable and clean energy to promote renewable energy and energy-efficient technologies, SDG 9, which aims to support sustainable industry and infrastructure, and SDG 11, which refers to resource efficiency and environmental protection in cities and communities, are other relevant goals that may become relevant to the topic at hand (Hák et al., 2016).

2.2. Green economy in Egypt

The Ministry of Planning, Monitoring and Administrative Reform presents the "Sustainable Development Strategy: Egypt Vision 2030", which addresses the challenges of the development process in Egypt. These challenges are the scarcity of natural resources such as energy, agricultural land and water (in addition to environmental degradation), human development resources including population, health and education, the inadequacy of the governance system and the lack of systems that foster creativity and innovation. In addition, the strategy sets out a series of goals and targets to transform these elements into incentives for development rather than major challenges. The development concept is based on the three dimensions of economic, social and environment and the concepts of sustainable and inclusive growth and balanced regional development. In addition, the strategy takes into account the principles of equal opportunities, bridging some development gaps, the optimal use of resources and supporting the fairness of their usage, and ensuring the rights of the next generations.

Egypt's green economy transition strategy incorporates the international principles of the green economy and its intended goals. This strategy aims to broaden the range of goals set for specific sectors, under the responsibility of the Ministry of Environment, which has paid great attention to the protection of the environment and natural resources, as well as the relief of these resources. Several parties are involved in the implementation of development policy towards a green economy. These parties have the mandate to implement the sustainable development goals on the topics of energy, transportation, industry, agriculture and institutional measures (Khawaga et al., 2021).

The transition towards a green economy brings with it various challenges and opportunities. The creation of new employment opportunities in the renewable energy and energy efficiency sector, resource efficiency and circular economy, and sustainable agriculture transition could lead to economic improvement. The social opportunities include further development of public health by reducing pollution and improving waste management practices. In addition, better access to electricity can be created through the promotion of renewable energy sources. The challenges include the financing of the transformation to a green economy, the development of policies and institutional framework, promote the required capacity building, raise awareness among the consumers and the public, and set the economic structures needed such as eco-systems and clusters for a just transition. A green economy can have a significant positive impact on sustainable development in Egypt, but there are several challenges that need to be considered. These challenges comprise poor infrastructure, lack of funding, and lack of awareness and education about the green economy (Muhammad, 2022). Considering the imperative need to address these challenges, Egypt has made notable strides in laying the groundwork for a sustainable and environmentally conscious future. By acknowledging the pressing issues of poor infrastructure, funding constraints, and the imperative necessity for increased awareness and education about the green economy, Egypt has demonstrated a firm commitment to navigate these obstacles. Building upon this commitment, Egypt has established a robust framework to combat the adverse effects of climate change and ensure the nations' resilience. This dedication was reflected in the formulation of the National Strategy for Climate Change Adaptation and Disaster Risk Reduction in 2011, which marked the initial steps towards a comprehensive approach to climate mitigation. Subsequently, in 2018, the alignment of the Low Emission Development Strategy (LEDS) with the Sustainable Development Strategy SDS - Egypt Vision 2030 illustrated a cohesive and forward-thinking approach in pursuit of a sustainable and environmentally responsible trajectory.

However, there is still a need to consolidate all climate change aspects into an integrated national strategy that includes climate considerations into all sectors of the country. As a result, the National Council for Climate Change (NCCC) has requested the development of a comprehensive National Climate Change Strategy for Egypt until 2050, which has been launched in May 2022. The main objectives of the NCCS 2050 include maintaining sustainable economic growth, reducing polluting emissions, promoting renewable energy, advancing green technology research, utilizing waste for energy production, and adopting alternative energy forms like green hydrogen. Additionally, the NCCS 2050 emphasizes enhancing resilience and adaptation to climate change, aiming to fortify Egypt's capacity to withstand climate shifts. Crucially, the strategy also focuses on establishing robust climate finance infrastructure to ensure the effective allocation of resources for climate initiatives. Furthermore, it seeks to refine climate action governance, thereby ensuring that climate-related policies and actions are well-coordinated and impactful, aligning with the broader goal of sustainable development and environmental stewardship (EEAA, 2022).

The Egyptian government has prioritized the transition to a green economy as a key development agenda. The current target is to raise the level of investments in the green economy from 30% to approximately 40% of the total public investment by 2023/2024, with a subsequent target of reaching 50% by 2024/2025 (Egypt Today, 2023)[2]. The transition to a green economy is facilitated, among other initiatives, by the government's sustainable financing framework, which includes tax exemptions for green hydrogen projects and a commitment to channel 50 per cent of government investment into environmentally sustainable projects. Investments are also supported by a high-level investment council and the Green Economy Financing Facility, which promotes private sector engagement and foreign direct investment (Daily News Egypt, 2022; Egypt Green Economy Financing Facility, 2022; EBRD, 2023).

2.3. Egypt's economy

Egypt is the largest economy in North Africa and had the third highest Gross Domestic Product (GDP) among African countries, after Nigeria and South Africa in the year 2021 (IMF, 2023a). The GDP per capita in Egypt in 2022 was US$4,295.4 (World Bank, 2023a). Until the outbreak of the COVID-19 pandemic Egypt had a fast-growing economy. Egypt's GDP has been growing at an average annual rate of 4.3% since the 1990s, which is higher than the African average. During the pandemic, the Egyptian economy continued to grow by 3.3% in 2020 (ibid.).

Egypt is a country with a rich history and culture and a growing population. At the beginning of 2022, Egypt's total population was nearly 103 million (CAMPAS, 2022a). Although annual population growth dropped to 1.86% in 2021 (World Bank, 2023c), Egypt is expected to reach nearly 115 million by 2027 (IMF, 2023c). The population structure is characterized by high population density (nearly 108 inhabitants per square kilometer; year 2020) (CAMPAS, 2022a), with nearly half of the total population living in urban centers such as Cairo and Alexandria (42.86%; year 2021) (World Bank, 2023b). Cairo is Egypt's largest city, with a population of 21.3 million (World Bank, 2022). In 2022, 62.31% of Egypt's population was between 20 and 64

[2] For further information, see also UNEP (2014) and UNFCCC (2023)

years of working age (World Bank, 2023d) and worked in sectors such as agriculture, construction, trade, manufacturing, and education (Dcode, 2021a). However, the share of employed persons has been declining, with the ratio of employed persons to the population falling from 45% in 2010 to 38% in 2020 (ILO, 2022). Figure 1 provides an overview of the key facts about the Egyptian economy.

Factsheet Egypt	
Population (2022)	103 Million
GDP per capita (2022)	US$ 4,295.4
GDP annual growth (2022)	6.6%
Annual greenhousgas emissions per capita (2019)	3.5 tonnes CO_2 equivalent
power generated by renewable energy resources (2021)	5% (0.21 quadrillion British thermal units)
Unemployment rate (2022)	7%
Globale Gender Gap Index (2023)	0.6

Figure 1 Key socio-economic indicators for Egypt for 2019-2023

Sources: CAMPAS, 2022b; World Bank, 2023a; IMF, 2023b; Simões et al., 2022; EIA, 2023; ILO, 2023; World Economic Forum, 2023

In 2019/2020, manufacturing was the sector that contributed the most to Egypt's GDP: It generated up to 16.1% of GDP. This was followed by the wholesale and retail trade sector and the agriculture, forestry and fishing sector, which accounted for 13.6% and 11.3% of GDP respectively. In contrast, the water and information sector accounted for the smallest share of the country's GDP, at around 0.5% (Dcode, 2021b). Figure 2 shows the distribution of Egypt's GDP by sector for 2019/2020.

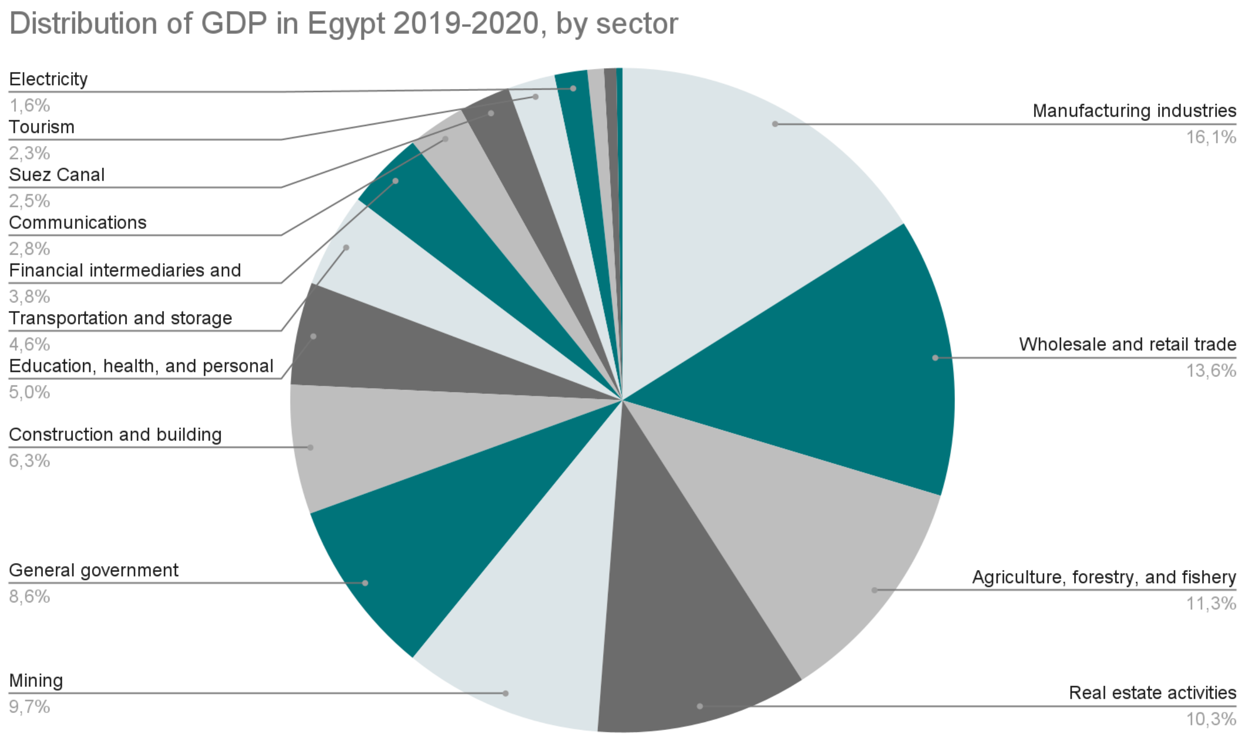

Figure 2 Distribution of GDP in Egypt in the years 2019-2020

Source: Dcode, 2021

Since Russia's war against Ukraine, economic activity in Egypt has slowed down. Rising food prices, driven by inflation (from 4.5% in 2020/2021 to 8.5% in 2021/2022) and currency depreciation have disproportionately affected the poor. Despite this, consumption has been supported by fiscal packages, and unemployment and informal jobs have remained relatively stable (OECD, 2023).

Egypt's energy mix

Egypt's energy mix heavily relies on fossil fuels, particularly oil and gas, as the backbone of its economy, constituting approximately 94% of its energy sources (IEA, 2023). The total final energy consumption in Egypt is mainly driven by the transport and industry sectors. Looking ahead, both these sectors, along with the residential sector, are projected to experience the most significant growth in energy consumption by 2030 (European Investment Bank, 2013). Natural gas was the source with the highest share with 61.6% of the total energy production. Petroleum and other liquids came next with roughly 33.3 %, while renewables and others' share was only 5% (EIA, 2023).

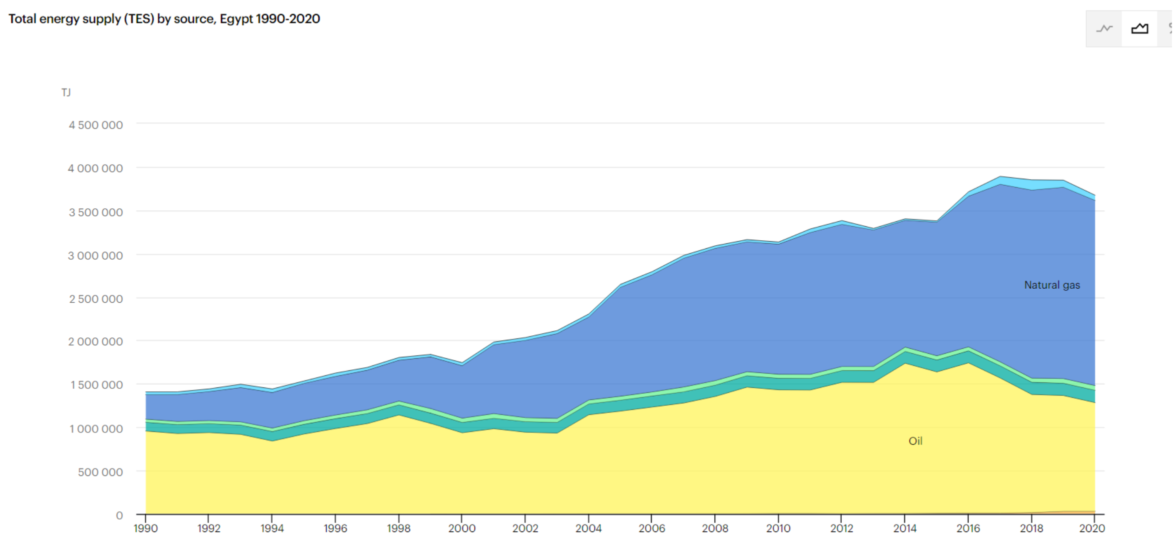

Figure 3 Total energy supply (TES) by source, Egypt 1990-2020

Source: IEA, 2023

Private sector & Small and Medium Enterprises in Egypt

In 2021, the government published plans to increase the role of the private sector in the economy through a second round of economic reforms (U.S. Department of State, 2022). In recent years, SMEs have become the dominant form of business in Egypt, accounting for about 98% of total private sector activity, which contributes about 43% of Egypt's GDP (Daily News Egypt, 2022; Zaazou, 2021).

The categorization of micro, small and medium enterprises (MSMEs) in the present report is based on the definition of MSMEs by the Central Bank of Egypt (Chapter 7. Egypt)[3]: Accordingly, existing enterprises are classified as ...

- Micro-enterprises, if their annual revenue is less than 1 (EGP million) and the number of employees is less than 10.
- Small enterprises, if their annual revenue is between 1 and 50 (EGP million) and the number of employees is less than 200.
- Medium-sized enterprises if their annual revenue is between 50 and 200 (EGP million) and the number of employees is less than 200.

Since the late 1900s and early 2000s, SMEs in Egypt have been supported by the government, resulting in an exponential growth in their number. This trend can also be attributed to the limited availability of employment opportunities in the private sector, so individuals have turned to setting up SMEs as a means of livelihood (Abdelaal, 2023). There are an estimated 3 to 8 million micro-enterprises and around 67,000 small businesses registered in the country (ibid.). However, a large proportion of Egyptian MSMEs are informal and not registered in the formal MSME systems (Bary, 2019). Most MSMEs are engaged in wholesale and retail trade (58%), followed by manufacturing (14%) and services (9%), then accommodation and food services

[3] Both terms, 'SMEs' (Small and Medium-sized Enterprises) and 'MSMEs' (Micro, Small, and Medium-sized Enterprises), are considered equivalent and are utilized based on the terminology employed in the respective sources.

(tourism) (5%), followed by health and social work (4%) and agriculture / forestry / fishing (4%), with the remaining 7% in other sectors (Gray et al., 2022).

SMEs play a crucial role in driving economic development through their contributions to increased production, job creation, export growth, and the fostering of innovation and entrepreneurial skills. However, there are some challenges in the structure of the Egyptian MSME sector, in the area of financing, legal frameworks, innovation or general guidelines (Bary, 2019). Furthermore, the transition from informal micro and small enterprises to medium-sized formal ones, could be promoted in a conducive business environment that facilitates the progression and mobility (ibid.).

Although MSMEs play a crucial role in economic development and growth, their environmental performance is often less scrutinized. Although they may produce small amounts of pollutants individually, their overall pollution can be very high. At the same time, MSMEs in Egypt are significantly affected by the impacts of climate change due to their limited resources and capacity to adapt to these changes. In particular, smaller enterprises, such as smallholder farmers, face major challenges. Barriers to establishing a support system for MSMEs include the fact that supporting SMEs is more complex, individualized and costly than supporting larger farms, and that access to these smallholders, especially in remote areas, remains difficult (International Food Policy Research Institute, 2022).

In addressing the substantial environmental impacts of MSMEs and particularly their vulnerability to climate change and limited adaptive capacity, the Resource Efficiency and Cleaner Production Program (RECP) stands out as a strategic solution, offering a pathway to enhance productivity, competitiveness, and new business models for enterprises. As a joint UNIDO and UNEP initiative, the program aims to support resource efficiency and environmental performance at national, regional, and global levels for enterprises (Ashton et al., 2018; Szilagyi et al., 2018). However, challenges persist due to limited information, financing, and institutional support, requiring the adaptation of financing instruments to incentivize RECP initiatives (Vieira & Amaral, 2016; Ongechi et al., 2021; Szilagyi et al., 2018).

2.4. Value chain selection

In order to identify relevant value chain cases for supporting a green private sector transition in Egypt, a criteria-based secondary data analysis was conducted as a first step. The underlying criteria are assumed environmental relevance, economic relevance with a focus on SMEs in Egypt and GIZ involvement in Egypt in terms of sectors (agribusiness and manufacturing). The selected value chaines analysed in this report are: cotton, sugar beet, refrigerators (cooling value chain).

2.4.1 Cotton

In Egypt the cotton and textile industry is an important sector in the country's industrial development strategies. The textile and apparel (T&A) sector employs more than half a million people, contributes about 3 to 4% of Egypt's GDP, and accounts for almost 23% of employment in Egypt's industrial sector (Fahim, 2023). The sector is one of the most important industrial sectors in terms of value added, employment, and exports, with T&A exports accounting for about 12% of total exports in 2018 (Grumiller et al., 2020; Fahim, 2023).

After 1952 until the 1990s the textile and apparel sector in Egypt was dominated and highly regulated by public enterprises. The structure of this sector changed in the early 1990s by economic reforms and privatization. With this, privately owned companies gained in importance (Raza et al., 2020). The Cotton production in Egypt amounted to 58,000 tonnes in the 2020/2021 season (Textile Exchange, 2022). Egyptian cotton is seen as the gold standard for the finest linen and clothing in the world. Egyptian cotton, with its high-quality fibers, is one of the finest and most lustrous varieties (Gallico, 2020).

The overview below shows the different firms that are active in the Egyptian textile sector, including 80.8 % micro and 11% small-scale enterprises and large enterprises (0.2%) (Roberts, 2021). Micro- and small-scale enterprises are thus at the forefront of environmental protection and resource-efficiency. They need sustainable investment to be able to purchase modern machinery and upgrade their activities, train and hire skilled labor and to invest in efficient energy supplies, such as photovoltaic as well as to tap into European markets that are increasingly asking for transparent and traceable best practices in social and ecological performance (Gallico 2019; Grumiller 2020; Roberts, 2021).

This study focuses on cotton and textile (yarn/fabric) production with special attention to the cotton chain. Cotton and Textile production plays an important role in the Egyptian economy (Gallico, 2019).

Egyptian cotton and textile market

Egypt's textile industry, anchored by the renowned Egyptian cotton, plays a crucial role in the nation's economy. This chapter delves into the unique qualities and market dynamics of Egyptian cotton, explores the broader textile market's landscape, and sheds light on the industry's organizational structure.

Egyptian Cotton – characteristic, market and producers

Egypt's renowned extra-long staple cotton Gossypium barbadense, known as "white gold", thrives along the humid Nile River region. Its superior quality, with exceptional length and luster, makes it highly durable, which is why it's preferred by luxury brands. Handpicked to ensure consistency, this premium cotton is typically reserved for fine home textiles, while shorter staples are used in apparel (Gallico, 2019; USDA 2019; EI - C, 2023).

Egypt's cotton cultivation is centered in the Nile Delta, with the bulk of production spread across five northern districts: Kafr El Sheikh, Behera, Dakahlia, Sharkia, and Gahariba. Smaller growing areas dot the Nile, yielding 1,000 to 10,000 bales each. Sowing occurs from March to May, and harvest from September to December. Over the past five years, the average cultivation area was 106,000 hectares, producing 343,000 bales annually, with yields averaging 704 kg per hectare (Abdallah, 2012; USDA/IPAD, 2023).

Cotton cultivation in the country is planned by the Ministry of Agriculture. Two months before the start of the planting season, the Ministry issues a decree specifying the varieties of cotton allowed for planting, separated by region. According to this decree, each variety may only be grown in the specified areas (USDA, 2022).

Egypt's cotton production reached 58,000 tonnes in the 2020/2021 season and is projected to rise to 320,000 bales in 2022/2023 from 280,000 bales in the previous year, reflecting increased demand. The cultivation area is also expected to expand by 14% to 97,000 hectares from 85,000 hectares, continuing the growth trend into 2022 (Textile Exchange, 2022; USDA, 2022).

Egyptian cotton, comprising only 5% of Egypt's textile market, contrasts with the 95% market share of non-Egyptian cotton. Efforts to boost Egyptian cotton include the Egyptian Cotton Project, Cotton for Life, and the Better Cotton Initiative (EI - C, 2023). Despite not producing denim, Egypt exports cotton bales, imports denim, and then re-exports denim products (EI – C, 2023). In 2019, exports of unprocessed cotton reached nearly $170 million (Statista, 2022). About 75% of raw cotton exports are sent to low-wage countries for processing into yarns and garments. Major export markets include Asia, the EU, and the Middle East (Gallico, 2019). The Egyptian textile industry relies on imported shorter cotton fibers for garment production, primarily from India, Bangladesh, and Pakistan (EI – C, 2023).

In the field of organic cotton production, Egypt has a long standing reputation as a major producer of extra-long organic staple cotton and in 2020/2021 grew an estimated 437 tonnes of organic cotton fiber on 404 hectares of certified organic land (Textile Exchange, 2022). Most activities in the Egyptian organic cotton sector appear to revolve around one of the leading actors, NaturTex, one of the four subsidiary companies of Sekem Holding (Rota et al., 2018). Exporters mentioned in the interviews the key distinctions between organic and conventional cotton cultivation. Organic cotton farming takes a holistic approach that emphasizes environmental sustainability and minimizes the use of synthetic chemicals (EI - C, 2023). Unlike conventional methods that rely on synthetic pesticides and fertilizers, organic cotton farming uses natural and environmentally friendly techniques (EI - C, 2023). These include the use of organic fertilizers, crop rotation, and biological pest control. In addition, organic cotton farming avoids genetically modified organisms (GMOs) and uses certified organic seeds (EI - C, 2023). According to the expert interviews, organic certification is already achieving important results in terms of the sustainability of the textile industry (EI - C, 2023). It already takes into account recommendations for the use of renewable energy as an energy source, and this certification system is becoming an increasingly comprehensive tool for the transition to a green economy (EI - C, 2023).

Egyptian textile market

According to Gallico (2019) Egypt plays a marginal role in the global textile value chain as its textile industry is highly fragmented and its textile products do not meet the needs and demands of the global market. Contrastingly, other sources state that Egypt's cotton and textile industry is highly productive. For example, Raza et al. (2020) state that the textile industry in Egypt offers a full production chain and a major advantage of the Egyptian textile industry is the domestic availability of cotton as a key raw material. The Egyptian textile industry accounts for 4% of the country's

GDP. It employs almost 23% of Egypt's industrial workforce, which is about 2.5 million workers and accounts for 12% of Egypt's non-petroleum exports (Fahim, 2023). It is the second largest industrial sector in Egypt (Fahim, 2023).

The textile industry accounts for 12% of Egypt's export earnings (Egypt Business Directory, 2023). Egypt imported 1,332 thousand tons of textile material and exported 283 thousand tons of yarn and fabric in 2019. The exported garments (52.8% of exports) are largely based on imported yarns, and finished fabrics and home textiles (25.4% of exports), which are made from domestic yarns and fabrics (Gallico, 2019). Of the produced cotton, 16% is consumed locally, 72% is exported, and 12% remains in stock (Raza et al., 2020).

Despite a strong export quota, Egypt imported more goods than it exported, resulting in a trade deficit in the textile sector (Switchmed, 2022). The main export items are denim (yet not from Egyptian cotton - see above), other woven fabrics, cotton yarns and non-woven textiles (Egypt Business Directory, 2023). According to the expert interviews, certifications and sustainability criteria are needed to export finished products to the EU or to the USA (EI - C, 2023).

Excursus – Definitions

Textile: Any material consisting of interlacing fibers, including carpets and geotextiles. That means that any woven or knitted fabric is a textile. All textiles have in common that they are made from textile fibers (Cornellier, 2020).

Fabric: A two-dimensional mass consisting of fine-soft objects connected by intersecting, winding and joining (Cornellier, K., 2020).

The above-mentioned terms are often used as synonyms in the literature, therefore no clear separation can be made here.

Apparel: Apparel does not only include clothes or garments. Above that it also includes watches, hats, bags, various jewelry, etc. Clothing and accessories are called apparel (Rony, n.d.).

Ready made garment: A garment is any type of clothing made of fabrics or other textile materials intended for use on the human body. Garments are also called ready-made-clothing because they are made from different fabrics (Rony, n.d.).

Textiles and apparels are produced both for the local market and for export. The domestic textile industry uses for the most part imported short- and medium-staple cotton. These are often imported at higher cost due to non-tariff barriers and small orders. Denim items and T-shirts are among the common Egyptian products that use short staple-cotton. The textile sector also relies on imports of man-made fibers due to limited local production (Raza et al., 2020). However, the Egyptian textile sector also has major advantages, such as local availability of extra-long-staple cotton, low production costs, duty free and quota free access to the US and EU markets, which belong to the key consumption markets (Raza et al., 2020). Furthermore, Egypt has competitive wages (Raza et al., 2020). Due to Egypt's geographical location, it has very good transport links to Europe, Africa and the Middle East. This makes it ideal for the textile industry (Egypt Business Directory, 2023).

Company structure in the textile sector

Until Egypt joined the WTO in 1995, the textile and apparel sector was dominated by public enterprises and strongly regulated by the state (Midani, 2019). WTO membership required Egypt to promote free trade and the reduction of tariffs, quotas, and trade barriers. Consequently, competition with Asian low-cost imports was on the rise (ibid.). With this, privately owned companies gained in importance (Raza et al., 2020). The decline of the state led textile industry in Egypt can be attributed to the use of outdated equipment, especially in state-owned enterprises. Many of Egypt's textile mills are equipped with outdated technologies that are not suitable for processing Egyptian long-staple-cotton. While modernization of enterprises by the government is taking place, Egypt’s large domestic textile industry is highly dependent on imports and lacks vertical integration (Gallico, 2019; ICAC 2022).

The following tables provide a comprehensive overview of the textile sector in Egypt, covering the number of firms, registered companies, exporting firms and their respective market shares. It highlights the significant contribution of the textile sector to the Egyptian economy, with over 85.000 establishments, 32.000 registered companies, and thousands of exporting firms actively engaged in various segments of the industry.

Category	**Data**	**Reference source**	**Page**	**Source year**
Number of establishments in the overall textile sector	85,000 (from 2018)	CAPMAS from Egypt Business Directory	-	2023
Assessment reported active companies	not more than 8,000	EI – C	-	2023
Private companies	2,500 to 3,500	Gallico et al.	112	2019
State-owned enterprises	25 (5% of production, 65,000 employees)	Ceeba	11	2021
Total formal sector enterprises	6,742 (526,150 employees)	Ceeba	11	2021
Textile-only companies range	3,500-6,500	Egypt Business Directory	-	2023
Market supply by state-owned mills	50-60%	Ceeba	9	2021
Enterprise size distribution	88.8% micro, 11% SMEs, 0.2% large	Roberts	23	2021
FDI-created companies (2016-2019)	452 new companies	Egypt Business Directory	-	2023

Exporting Firms

Category	Data	Reference Source	Page	Source Year
Exporting firms (total)	1,310	Raza et al.	23	2020
Cotton exporters	84	Raza et al.	23	2020
Yarn to fabric exporters	150-250	Raza et al.	23	2020
Apparel exporters	700	Raza et al.	23	2020
Companies in export sector	500-600	Ceeba	9	2021

Table 1 Overview: Firms in the textile Sector

Source: Own illustration

Challenges and Opportunities for SMEs in the Egyptian Cotton Industry

Limited inventions in spinning, weaving, knitting and dyeing processes resulted in bottlenecks contributing to the textile sector's high dependence on imports. According to the expert interviews there are two central challenges. First, there is a pronounced deficit in the use of technology and a noticeable lack in the adoption of modern global advances in this area (EI - C, 2023). This technological lack not only affects efficiency, but also limits the industry's ability to remain competitive at the international level. Second, the challenge of unrestricted trade (free trade) further exacerbates the situation. The unregulated influx of cotton products from various markets poses a threat to cotton growing regions and undermines the viability of the local textile industry. These dynamics of unregulated trade underscore the urgency of strategic action to protect the domestic cotton sector and promote sustainable growth across the textile landscape. Addressing these challenges requires a multi-faceted approach that includes technology integration, policy promotion, and market balance (EI – C, 2023).

As mentioned by the interviewed experts, Egypt has a growing private SME sector that plays a key role in the Egyptian economy (EI -C, 2023). However, there are strong public enterprises operating in several sectors of the economy and competing with private SMEs. Another challenge and chance for SMEs is that in the export segments to the EU they are increasingly confronted with meeting the dynamic EU regulations on green economy and decarbonization (EI - C, 2023). Simultaneously, the shift towards eco-friendly industrial practices and the adoption of a green economy opens up avenues for development within the private SME sector. These enterprises stand to benefit by offering specialized services for the implementation of sustainable practices, reducing operational costs tied to energy consumption and raw material procurement. Moreover, the integration of green practices enables SMEs to promote their environmentally conscious products and cater to discerning markets, including those emphasizing the import of sustainable goods (FGD - C, 2023).

Politically, the overall objective is to further develop the cotton and textile sector with integrated domestic value chains. It is an important pillar of Egypt's Vision 2030 strategy (Raza et al., 2020; FGD - C, 2023). One example for the promotion is that the Egyptian government plans to establish the world's largest spinning and weaving mill in Mahalla al-Kubra (Egypt Today, 2023). This has a cost of about 900 million Egyptian pounds ($57 million) (USDA, 2022).

Among the most important subcontracting sectors of the textile industry are the spinning and weaving sub-sectors. Most of the spinning and weaving capacities are owned by medium to large public enterprises (Gallico, 2019). Producers in the spinning and weaving sector have limited ability to respond to consumer demands, this is due to the dominance of the public sector. In addition, the sector is burdened with overemployment, inferior technology, operational inefficiencies and low capital utilization. There are weak linkages between spinning mills and garment manufacturers. In order to supply the ready-made garment industry, some yarns and finished fabrics are imported from India, Turkey, Turkmenistan, Bangladesh, Pakistan and other countries. Some finished fabrics made of Egyptian cotton are produced in Egypt, processed abroad and exported back to Egypt (Gallico, 2019).

2.4.2. Sugar beet

Agriculture is a key sector in the Egyptian economy. It contributed 11.83% to the country's GDP and provided 28% of total employment (World Bank, 2022). Especially in Upper Egypt, where more than half of the population lives below the poverty line, 55% of all employment is linked to agriculture (USAID, 2020). Most agricultural activities take place on small farms that use traditional methods in the Nile Valley and Nile Delta. However, these regions are facing land subsidence and decreased fertility, impacting agricultural productivity (Jungudo et al., 2023). Developing the agricultural sector is therefore crucial for poverty reduction, rural development, food security, gender equality and climate change mitigation.

With a production volume of 1600 MT and a share of 18% of all agricultural products, sugar beet is one of the most important crops, ahead of sugar cane (14%), wheat (10%), maize (8%) and potatoes (8%) (FAO, 2022[4]). Sugar beet, as Egypt's main sugar crop, are of immense economic importance, accounting for around 56% of sugar production in the 2022/2023 season (USDA, 2023). Accordingly, national sugar consumption is particularly high, at 30.6 kg of white sugar per person per year, above the global average of 22.1 kg and the African average of 14.6 kg (LEL, 2023). Despite the high level of production, national demand cannot be met by domestic production (see figure 4).

[4] FAO (2022) Crops and livestock. License: CC BY-NC-SA 3.0 IGO. Extracted from: https://www.fao.org/faostat/en/#data/QCL. Data of Access: 02.11.2023. And Sugar Beet Annual

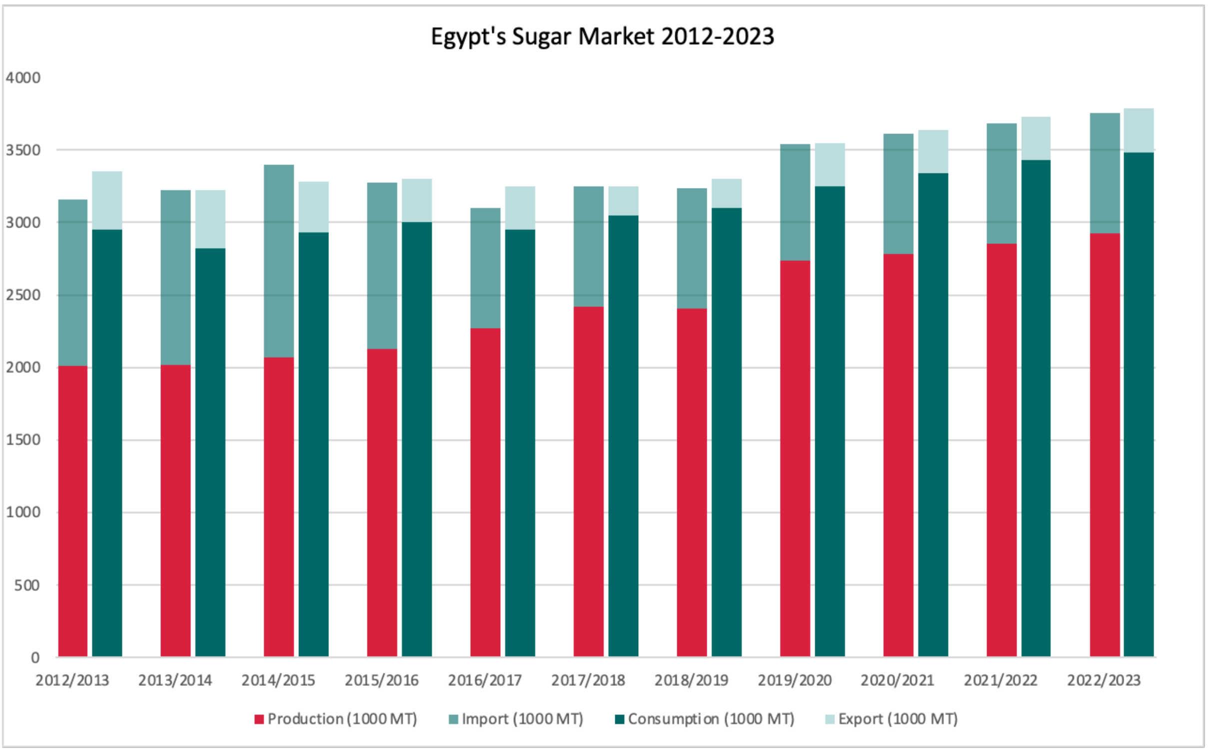

Figure 4 Egypt's sugar market 2012-2023

Source: Own illustration based on data from the USDA Reports (2012-2023)

As a consequence, the **area under cultivation and the processing quantities has been massively expanded in recent years** (USDA, 2023). In addition, Egypt is expanding the number of sugar factories, which is reflected in the increase in sugar beet area from 152 kha in 2011 to 190 kha in 2021 and the increase in production (USDA, 2023; FAO, 2023). As a result of increased sugar beet production, Egypt is expected to become the continent's largest sugar producer by 2032 (FAO, 2023). Consumption is increasing with population growth and the expansion of the confectionery sector. Imports are expected to increase to fill the gap between production and demand due to increased consumption (USDA, 2023).

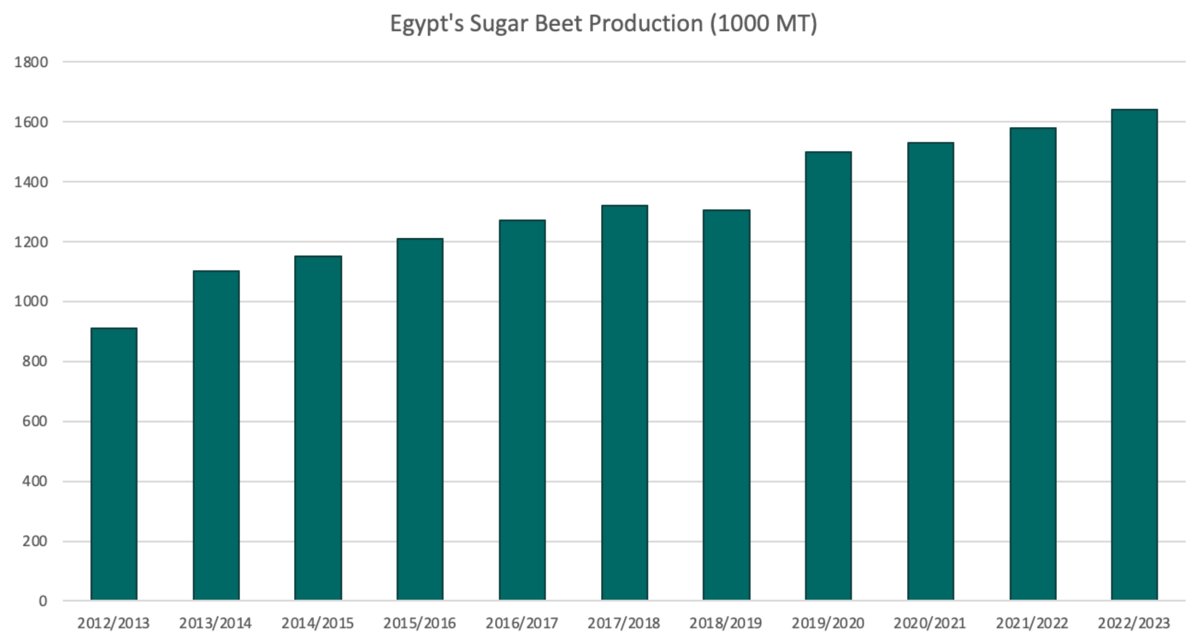

Figure 5 Egypt's sugar beet production 2012-2023

Source: Own illustration based on data from the USDA Sugar Annuals (2012-2023)

While further processing into refined sugar is exclusively dominated by 8 large producers, the cultivation of sugar beet is mainly characterized by small and medium-sized growers who enter into direct sales agreements with factories (USDA, 2023). The cultivation of sugar beet frequently depends on traditional practices with the use of manpower for some agricultural practices, such as removal of weeds, weed control, and the harvest of sugar beet. These growers operate with the sugar processing companies under contract farming arrangements. Additionally, some sugar beets are grown on leased land managed by privately-owned factories. The payment is not only based on the quantity of sugar beets but also on the sugar content. Thus, an optimal quality of the beets is crucial for farmers (EI - S, 2023). Additionally, factors such as maturity age, yield, and juice quality are influenced by the timing of harvests, which varies among sugar beet varieties (Yassin et al., 2022). In addition, the utilization of by-products can be particularly relevant for the private and SME sector. While the agricultural sector in sugar beet cultivation is mainly characterized by small and medium-sized farms, the processing phase is dominated by large companies, including some state-owned enterprises. According to the expert interviews this disparity in size and power can lead to conflicts between the stakeholders (EI - S, 2023). Of the eight sugar beet processors in Egypt, four are private sector and the rest are state-run companies (USDA, 2023). Among these, the top three factories include Canal Sugar Company in Minya, which holds the distinction of being not only the largest sugar factory in Egypt but also the largest globally. Canal Sugar cultivates sugar beet and operates a sugar factory for further processing. The factory covers 76,000 hectares of desert land and has an annual production capacity of 900,000 tonnes. The Al-Nouran Sugar Factory, covering an area of 177.45 hectares and having a beet processing capacity of 241,000 tonnes per year, is estimated to have a white sugar refining capacity of 1,768 tonnes per year (Al-Nouran Sugar Factory, 2020). Delta Sugar Company (Kafr El Sheikh) is the oldest sugar beet factory in Egypt, and all of its sugar production is consumed domestically. The company refines imported raw sugar and sells sugar produced earlier in the season. The factory has a beet capacity of 10,000 tonnes per day, produces 1,200 tonnes of white sugar per day and the total production capacity accounts for 300,000 tonnes per season (Delta Sugar Company, n.d.).

Egypt, situated in one of the world's most water-scarce regions, faces heightened vulnerability to climate change impacts. According to the IPCC, the Nile-Delta where nearly 60% of Egypt's food is cultivated is identified as one of the three most at-risk megadeltas, directly affected by climate change by 2050 (Namdar et al., 2021; IPCC, 2022). As the country relies heavily on freshwater abstraction for irrigation from the Nile-Delta, Egypt is exposed to risks of water scarcity. However, these soils have seen a decline in organic matter content and available nitrogen due to the intensive agricultural practices and the cessation of silt deposits following the construction of the Aswan High Dam (Ouda et al., 2015). Projects such as the Grand Ethiopian Renaissance Dam will further affect Egypt's water supply, especially during dry years (Abdelhaleem et al., 2015). Declining water supplies will further limit irrigation, while rising sea levels will contribute to coastal flooding and salinization. The Nile Delta is the primary region for cultivating sugar beet and often referred as “Old Land”. Small-scale farmers who cultivate sugar beet in a conservative approach based on traditional practices are primarily found in this area. In contrast, the new land is an area that has recently been developed for agriculture. These areas are mainly located in the desert or semi-desert regions, where heavy irrigation is needed for successful crop cultivation. In addition, the soils are lime-rich or sandy and lack macro- and micronutrients, so there is a high demand for water and nutrients and the risk of erosion is high (Ouda et al., 2015). According to FAO (2016) all newly developed agricultural areas have to use sprinkler or localized irrigation, while surface irrigation, which is typically used in the old land, is forbidden. While sugar beet is predominantly grown in the delta region in upper Egypt, cultivation extends to the Minya governorate in Upper Egypt and Toshka (USDA, 2023). However, the first growing regions are also being developed in the new delta (EI - S, Focus Group Discussion, 2023).

In addition to the increasingly critical water supply, which is being driven even further by climate change in particular, **agriculture itself is responsible for greenhouse gas emissions**, which is why sugar beet was selected as a case study. Land use and land use change (conversion of forest, grassland and lowland moorland to agricultural land) releases carbon stored in biomass in the form of CO_2. Furthermore, in agricultural soils, greenhouse gases such as nitrous oxide (N_2O) are generated as part of the nitrogen cycle. This occurs through processes like fertilizer application and microbial conversions of nitrogen compounds. In addition, the combustion of fossil fuels during the operation of agricultural equipment also produces CO_2 emissions (Meunier 2023; Örtl, 2022). Overall, agriculture, forestry and other land use accounts for about one fifth (22%) of global anthropogenic greenhouse gas emissions (OECD, 2023). In the subsequent stages of value creation, greenhouse gases primarily arise from the use of fossil fuels for energy production (energy requirements of refineries and fuels for transportation).

These cumulative challenges underscore the urgent need for comprehensive and sustainable solutions to safeguard the agricultural productivity and environmental integrity of the Nile Delta (Fishar, 2016).

Excursus: Sugar production from sugar cane
Within the last decade, the share of sugar beet in total sugar production continues to increase. In 2012/2013, the share of sugar beet was around 47%. Since then, beet sugar production has risen beyond the production of cane sugar, reaching 56% in 2022/2023 (Sugar Annuals, 2012-2023).
The processing of sugar extraction of beet sugar and cane sugar is nearly identical. However, there are significant differences when it comes to cultivation. Accordingly, opting for sugar beet over sugar cane presents a more sustainable choice for several reasons: Given Egypt's water scarcity, selecting the beet is the better choice as it has a lower water footprint compared to the sugar cane (Ibrahim, 2021). With regards to climate change, soil salination and rising water scarcity, sugar beets have the advantage to be better adapted to these conditions (Tahjib-UI-Arif et al., 2019; Khamidov et al., 2022; Ouda et al., 2015). Furthermore, the two crops significantly vary in cultivation methods: While sugar cane is cultivated in a monoculture over several years, sugar beet is an annual plant that seamlessly fits into crop rotation systems which provide different environmental benefits (Cheesman, 2004). In addition, producing sugar from sugar beets is more economically efficient compared to sugar cane (Expert interview - S, 2023).

2.4.3. Refrigerator

One sector in Egypt where small and medium-sized enterprises (SMEs) dominate the industry is the white goods sector (ILO, 2022). White goods are household appliances such as refrigerators, ovens, washing machines, tumble dryers, dishwashers, and air conditioners (MBN, n.d.). The majority of enterprises in the white goods sector in Egypt (93%) have fewer than 100 employees, and of the total number of enterprises in the sector, 67.6% are formally registered (ILO, 2022). The white goods industry in Egypt faces several challenges, including outdated technology, a lack of skilled labor, and a lack of technical, environmental and energy efficiency standards. In addition, ensuring the quality of the products to meet the standards and volumes required by the large global companies is a further challenge (ILO, 2022).

Within the white goods sector in Egypt, refrigerators are an important category to meet the growing demand for cooling solutions in various sectors (MBN, n.d.). The industry is beginning a transition from its current high import dependency to local manufacturing with the potential to export appliances to the MENA region. Recent economic conditions, such as inflation, have made the country more attractive to refrigeration manufacturers. Although the market is currently dominated by large companies such as Electrolux, Fresh Electric, BEKO or global brands such as Toshiba, these changes offer potential opportunities for local SMEs to become more involved in the refrigeration industry in Egypt. This is particularly true for the production of parts such as doors, glass panels, shelves, magnets and gaskets (EI - R, 2023).

In this study, a refrigerator is defined as an electrical appliance used for the short-term refrigerated storage of perishable food and other household products. Its main function is to maintain a constant and cool temperature range between 2°C and 9°C to ensure the freshness and longevity of the stored contents (University of Hamburg, n.d.). Refrigeration is important for maintaining the safety and quality of many foods, as well as their delivery and consumption in an increasingly urbanized world (James et al., 2017).

- **Domestic Refrigeration:** A domestic refrigerator is a common household appliance without which the modern refrigerated food chain would not be possible. A typical domestic refrigerator has 230 litres of refrigeration space (4°C) and 110 litres of freezer space (-18°C) for food and beverages storage, with an estimated lifespan of around 10 years of use (Lewandowska, 2021). Almost every household in the developed world has at least one refrigerator (Green Cooling Initiative, n.d.-b).
- **Commercial Refrigeration:** Commercial refrigeration systems are primarily used to keep perishable goods fresh or frozen. They are used in food retail outlets such as supermarkets, discount stores and bakeries. They are also used in cafés, restaurants and other commercial areas.
- **Industrial Refrigeration**: Industrial refrigeration ensures that products are kept cool throughout the cold chain (Green Cooling Initiative, n.d.-b). The entire cold chain includes, for example, refrigerated transport, refrigeration equipment and related components.

88 % of private households in Egypt owned a refrigerator in 2023 (statista, 2023a). The Green Cooling Initiative (GCI) provides an overview of emissions and appliances used in the cooling and air conditioning sector globally and for individual countries. As shown in Figure 6, GCI estimates that 15.3 million domestic refrigeration units and just over 1 million commercial refrigeration were in use in Egypt in 2020. The number of domestic refrigeration units is expected to increase over the next few decades, reaching about 40.3 million units by 2050 (Green Cooling Initiative, n.d.-a). For commercial refrigeration, the number is expected to reach about 1.5 million units by 2050 (Green Cooling Initiative, n.d.-a).

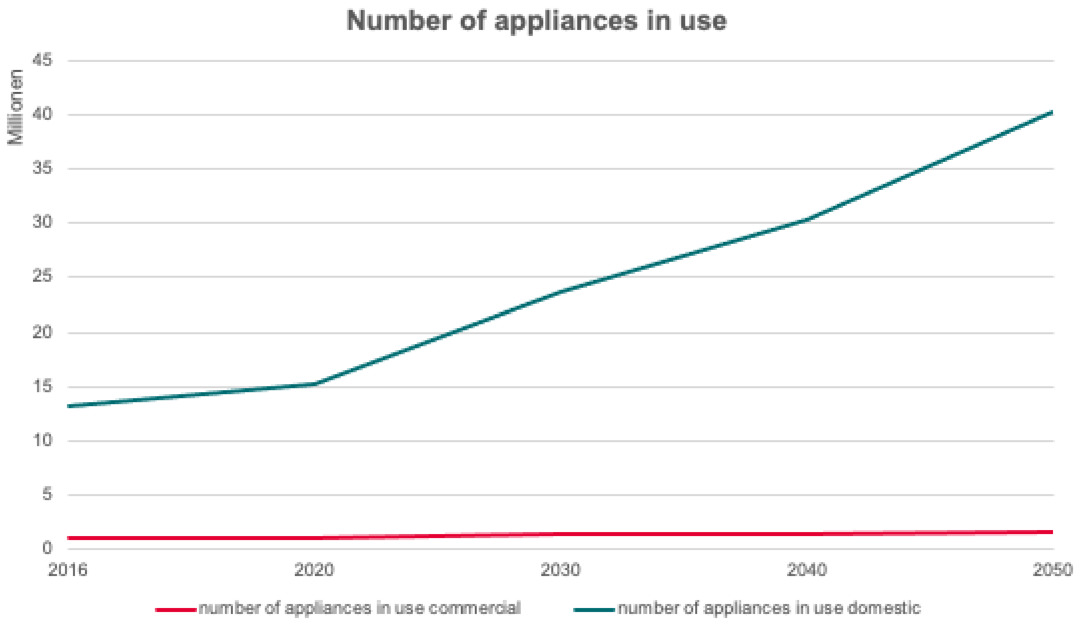

Figure 6 **Current and projected numbers of commercial and domestic appliances in use 2016 – 2050**

Source: Green Cooling Initiative, n.d.-a

The refrigerators sector is important due to its environmental impact in terms of greenhouse gas emissions and resource use (MBN, n.d.). The global cooling sector (including space cooling from air conditioning and refrigeration) was responsible for 10% of global greenhouse gas emissions in 2020 (Dong et al., 2021). In addition, global demand for cooling is expected to grow steadily as a result of rising global temperatures and population growth (Green Cooling Initiative, n.d.-a; EI-R, 2023).

According to the GCI, **total emissions from the refrigeration and air conditioning (RAC) sector in Egypt were estimated at nearly 20 Mt CO_2e in 2016, accounting for approximately 0.1% of the country's total CO_2 emissions** (231 Mt CO_2 in 2016) (The World Bank, n.d.-a). Total emissions are expected to increase to 46 Mt CO_2e by 2050 under a business-as-usual scenario or to 30 Mt CO_2e under a mitigation scenario (Green Cooling Initiative, n.d.-a). Refrigeration appliances are recognized as a major contributor to household electricity consumption in Egypt (Abed et al., 2015).

The climate impact of refrigerators can be divided into greenhouse gas emissions from energy consumption throughout the value chain and refrigerant leakage. Refrigerant is the fluid used for heat transfer in refrigeration systems (Bitzer, n.d.). GHG emissions from the generation of electricity and heat are relevant for the supply of energy for the use of the appliance, its manufacture and its disposal (Dong et al., 2021; Green Cooling Initiative, n.d.-c). Refrigerants can leak during its use phase and its disposal, which can be harmful to people and the environment. Indicators of the environmental impact of a refrigerant are the Global Warming Potential (GWP) and the Ozone Depletion Potential (ODP) (Darment, n.d.). Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are responsible for the depletion of the ozone layer. Both were widely used as refrigerants until these negative effects were identified (Dong et al., 2021). **The Montreal Protocol aims to phase out the use of CFCs and HCFCs in all developed countries by 2030 and in all developing countries by 2040** (Dong et al., 2021; UN Environment Programme, 2020). An alternative is climate-friendly refrigerants with a GWP of 20 or less and no ODP. The greenest option for refrigerant today is the hydrocarbon isobutane (R600a), which has a very low GWP of 3 (Green Cooling Initiative, n.d.-b; Dong et al., 2021). While European countries have almost completed the transition to natural refrigerants, there is still room for improvement in developing countries (Green Cooling Initiative, n.d.-c).

Refrigerators are made up of individual components that, when assembled, make up the appliance. These components include the cabinet, doors, shelves, compressor, insulation, gaskets, refrigerant and smaller components such as electronics and cables (Xiao et al., 2015). **A number of biotic and abiotic resources are used in the refrigerator value chain for their production, including iron ore for steel, aluminum, copper, glass and plastics such as polystyrene or polyurethane** (CECED, 2017; Lewandowska et al., 2021; Xiao et al., 2015). Figure 7 gives an overview of the materials and parts of a standard household refrigerator. The extraction of each of these raw materials involves energy-intensive processes such as mining and can have significant impacts on the environment and people, such as acidification, air and water pollution or soil toxicity (Kullerud, 2003; OECD Web Archive, 2018).

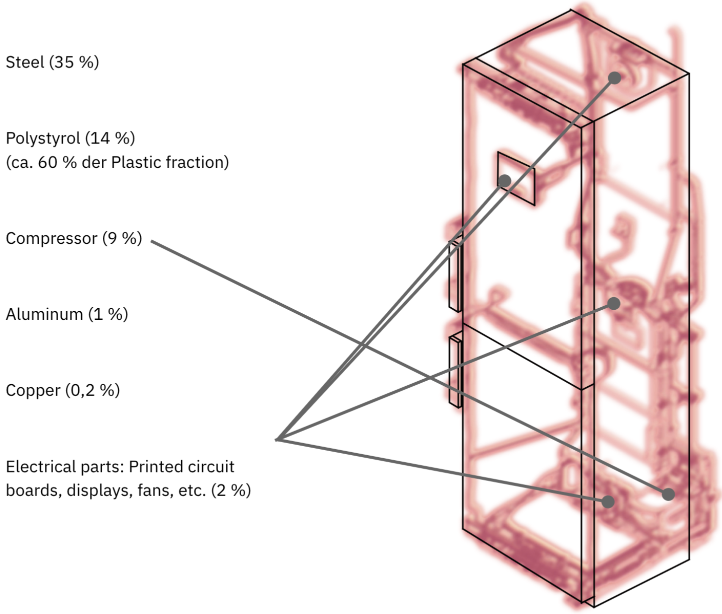

Figure 7 Materials with mass fractions of a domestic refrigerator

Source: Tochtrop & Heibeck, 2022

Excursus: Social impact of the refrigeration Sector

In addition to environmental impacts, the refrigeration sector also has social impacts. In 54 countries, covering poor rural and urban areas, approximately 1.09 billion people are vulnerable due to varying levels of access to refrigeration infrastructure. Economically disadvantaged populations may not have access to refrigeration at all, or face unreliable electricity supplies that prevent refrigeration from functioning effectively (Sustainable Energy for All, 2021). In addition to access to refrigeration services, the global refrigeration sector serves as an important source of employment, providing livelihoods for more than 15 million people worldwide (Dupont, 2019).

While this study focuses on the environmental impacts of refrigeration in Egypt, it does not neglect the importance of addressing the associated social impacts in further studies.

3. Research methods and data sources

The following chapter summarizes the applied methods in this study.

3.1. Methods

The following sections provide an overview of scientific methods that have been applied in this study.

3.1.1. Hot spot analysis

The hot spot analysis is an analytical, multi-criteria and development-oriented method that basically analyzes value chains in order to prepare decision-making at the action level and helps to structure and develop desired goal definitions of transition processes (Bienge et al., 2010). The hot spot analysis applied in this report focuses on the ecological impact of value chains along the product cycle. It is used to prioritize actions in the value chain and in the development process, to present and communicate product/service-related environmental aspects and can serve as a basis for target and scenario development, experiments, case studies and concrete action planning. Stakeholders and experts are involved at various points in the process.

The first step is to define an analytical framework and derive evaluation criteria. In order to make the analysis manageable, the scope of the analysis must first be reasonably delimited. As a rule, the product life cycle is subdivided into the phases "raw material extraction", "production/processing", "use incl. trade" and "disposal". On the basis of an extensive secondary analysis and expert interviews, typical or specific value creation paths and processes are identified for the selected value chains. Within this focused scope of investigation, ecological categories can be examined.

The second step includes the qualitative assessment of the categories and life cycle phases as well as the identification of hot spots. The most relevant ecological impacts along the life cycle are identified. For each category within each life cycle phase, the corresponding data is determined by means of desk research and, if necessary, supplemented by expert interviews. This is followed by a qualitative assessment of the relevance of the identified impacts on a scale from 1 = low relevance to 3 = high relevance. This assessment and the identification of hot spots involves three steps. First, the relevance of the categories within the individual life cycle phases is assessed. This is followed by a weighting of the life cycle phases among each other (also according to the above-mentioned relevance scale). Finally, the relevance of each impact categories is multiplied within each life cycle phase to identify hot spots. Thus, total scores between 1 and 9 points are calculated for each of the considered impact categories and life cycle phases. “Hot spots", i. e. particularly relevant impacts, are ratings with a score of 6 and 9 points.

In a third step, the stakeholder or expert evaluation takes place. This is where the results are validated and supplemented. Stakeholders with expert knowledge are involved in order to fill remaining information gaps on the one hand and to check the resilience and significance of existing results on the other. The assessments of the experts are then integrated into the evaluation of the results.

3.1.2. Stakeholder analysis and mapping

In order to effectively design and improve value chains for a green economy in Egypt, it is important to identify relevant stakeholders. The aim of the stakeholder analysis and mapping was to identify key stakeholders for each value chain in order to identify relevant stakeholders for the expert interviews and focus group discussions. Stakeholders in a value chain are defined here as all actors or organizations that influence, are affected by or have an interest in the respective value chain (Mathur et al., 2007). They include, but are not limited to, suppliers, processors, manufacturers, sellers, government agencies, investors, logistics providers, NGOs and other stakeholders who have an interest in the activities in the value chain.

The first step is therefore to identify the stakeholders that are directly or indirectly involved in or affected by each value chain, using a template and mapping approach. An Excel spreadsheet was used to collect the relevant stakeholders for each value chain. First, categories were defined in which individual stakeholders could be grouped, such as political actors, NGOs, manufacturers, etc. Then relevant stakeholders were identified and grouped (WHO, 2018). Figure 8 shows an example of the spreadsheet.

Stakeholder *Value Chain*

Category	Stakeholder	Stage of the value chain	Description	Website	XX	XX
Category 1						
Category 2						
Category 3						

Figure 8 Spreadsheet template stakeholder value chain

Source: Own illustration

In a second step, the identified stakeholders were mapped in a framework that visualizes the proximity of each stakeholder to the respective value chain. The value chain was thus placed at the center, around which the primary and secondary actors were grouped into three sectors: civil, private and public (SDC, 2021; Mathur et al., 2007). The definitions of the sectors and stakeholder categories are given below:

- Primary stakeholders: Identified stakeholders that are directly affected by or directly influence the respective value chain.
- Secondary stakeholders: Identified stakeholders that are indirectly affected by or indirectly influence the value chain.
- Key stakeholders: Selected experts to be interviewed for the respective value chain.
- Civil society sector: Civil society actors such as NGOs, faith-based groups, public figures, academics, individuals.
- Private sector: The private business or corporate sector, such as industry and commerce, SMEs.
- Public sector: public sector actors, such as government agencies and regulators.

Based on this mapping, relevant key stakeholders were identified for the expert interviews and focus groups. The identification of key stakeholders is based on an iterative process of desk research and consultation with local project partners, who have a comprehensive sector knowledge. Figure 9 shows an exemplary mapping framework.

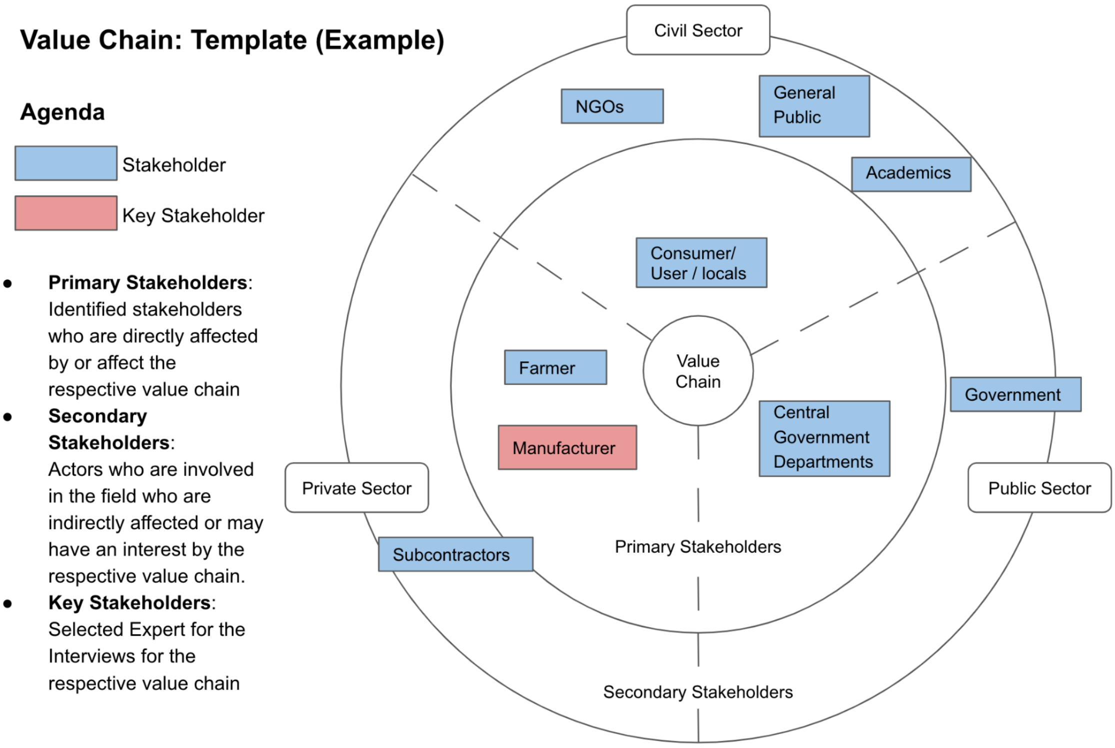

Figure 9 **Template of value chain mapping framework**

Source: Own illustration

3.1.3. Evaluation of greening options

As a third method, following the HSA and expert interviews, the identified greening options for each value were evaluated in the focus groups using a shortened version of a multi-criteria analysis (MCA). The assessments were carried out for each value chain by the participants of the focus group meeting in Cairo on 2, 3 and 4 October 2023. The aim was to assess the feasibility and suitability of the greening options for the local context in Egypt and intended to help make informed decisions about their implementation.

The MCA criteria were reduced to 4 key criteria to make the scope manageable for the focus group participants. The set of criteria is the same for all three value chains, so the identification criteria are generic. The four criteria are defined as follows:

1. Feasibility for private Sector & SMEs: This criterion assesses the practicality and affordability of implementing a greening option for the private sector with additional focus on SME, taking into account factors such as technology availability, technical compatibility, ease of implementation and cost effectiveness.

2. Climate Impact: This criterion assesses how a greening option contributes to mitigating or adapting to climate change by promoting climate-friendly or resilient practices. This criterion takes into account, for example, the reduction of greenhouse gas emissions or other measures that promote mitigation of and adaptation to climate change.
3. Resource Impact: This criterion assesses the impact of a greening option on resources such as water and other natural or synthetic materials or waste. It includes environmental impacts on the local ecosystem, such as pollution and biodiversity.
4. Social Impact: This criterion assesses how a greening option affects people and communities, including factors such as job creation, social equity, community well-being and its overall attractiveness to stakeholders, including investors, employees, consumers and societal support.

The actual assessment of the four criteria is based on a written description that qualitatively identifies the strengths and weaknesses of selected greening options. Its purpose is to provide a description of the strengths and weaknesses for each criterion for each greening option and not to provide a rating or conclusion to rank or determine the best greening option. In some cases, an evaluation criterion may not be relevant or applicable to a greening option, in which case a third category 'not applicable' may be selected. The three categories are defined as follows:

- Strength indicates that the greening option has a strength in a particular criterion.
- Weakness indicates that the greening option has a weakness in a specific criterion.
- Not applicable indicates that the criterion is not applicable to the greening option or cannot be assessed in its context.

An exemplary assessment is shown in Fig. 10.

	Strength	Weakness
Feasibility for private Sector & SMEs	• Cost effective • It will contribute to quality monitoring	• More adapted to manufacturers that export and less adapted to the local market.
Climate Impact	• Product lifetime will extend with positive impacts on climate	• Less awareness on the impacts of manufacturing on climate.
Resource Impact	• Product lifetime will extend with positive impacts on resources' saving and use efficiency.	
Social Impact	• Job creation	• consumers do not often consider these criteria

Figure 10 Exemplary assessment of greening options

Source: Own illustration

3.2. Data collection

3.2.1. Secondary data collection

Preliminary analysis of the literature, reports and documentation available for the three value chains was conducted. Initial stakeholder mapping and gaps were identified to address throughout the expert interviews.

3.2.2. Expert interviews

To collect qualitative data on the three value chains, expert interviews were conducted with the key stakeholders identified in the stakeholder mapping. The aim of the expert interviews was to verify the results of the HSA and to identify greening options for the respective value chains.

Expert interviews are characterized by the fact that the selection of interview partners is determined by their expert knowledge on a particular topic (Helfferich, 2014). The form of interviews conducted in this project were semi-structured expert interviews: structured interviews use an interview guide systematically, whereas a semi-structured interview uses a pre-defined set of questions and allows deviation from the order or wording during the interview (Magaldi & Berler, 2020).

In the period from 01.07.23 to 31.08.23, a total of 34 expert interviews were conducted by MENAES and YTG. 11 expert interviews in the cotton value chain, 8 in the sugar beet value chain and 15 in the refrigerator value chain. The experts came mainly from research organizations, public agencies, and private companies.

3.2.3. Focus group discussions

Three focus group discussions were held with local stakeholders in Cairo from 02.10.23 to 04.10.23 to verify the results of the HSA and to evaluate the greening options identified from the literature review and expert interviews. Each half-day workshop focused on one of the three defined value chains.

Time	Topic
9:30 - 10:00	Arrival & Welcome
10:00 - 10:15	Introduction: Goal & context of the project
10:15 - 10:35	Presentation of project design & interim results (value chain analysis, greening options)
10:35 11:20	Q&A and technical feedback
11:20 - 11:35	Preparation of focus group phase & clarification of questions
11:35 - 12:00	Coffee Break
12:00 - 13:30	Focus group work phase
13:30 - 14:00	Focus group results presentation
14:00 - 14:30	Summary & Outlook
14:30	End

Table 2 Agenda focus group procedure

Source: Own illustration

After an introduction of the goal and context of the project, the results of the HSA and identified greening options were presented. On this basis the participants provided an expert review and added further greening options. Based on a prioritization of greening options, a criteria-based discussion and evaluation of greening options has been carried out.

The participants of the FGD represented public institutions, research institutions, enabling agencies, private companies from three sectors and civil society organizations. In total 42 experts have been involved in the focus group discussions, 11 experts in the cotton value chain, 13 in the sugar beet value chain and 18 in the refrigerator value chain.

4. Cotton value chain

The following flow chart visualizes the different steps along the cotton life cycle. The system boundary of the analysis at hand is the investigation of the ecological hotspots of the following life cycle phases (see Figure 11):

- agricultural phase
- processing phase, including fiber production, yarn and fabric production, textile production

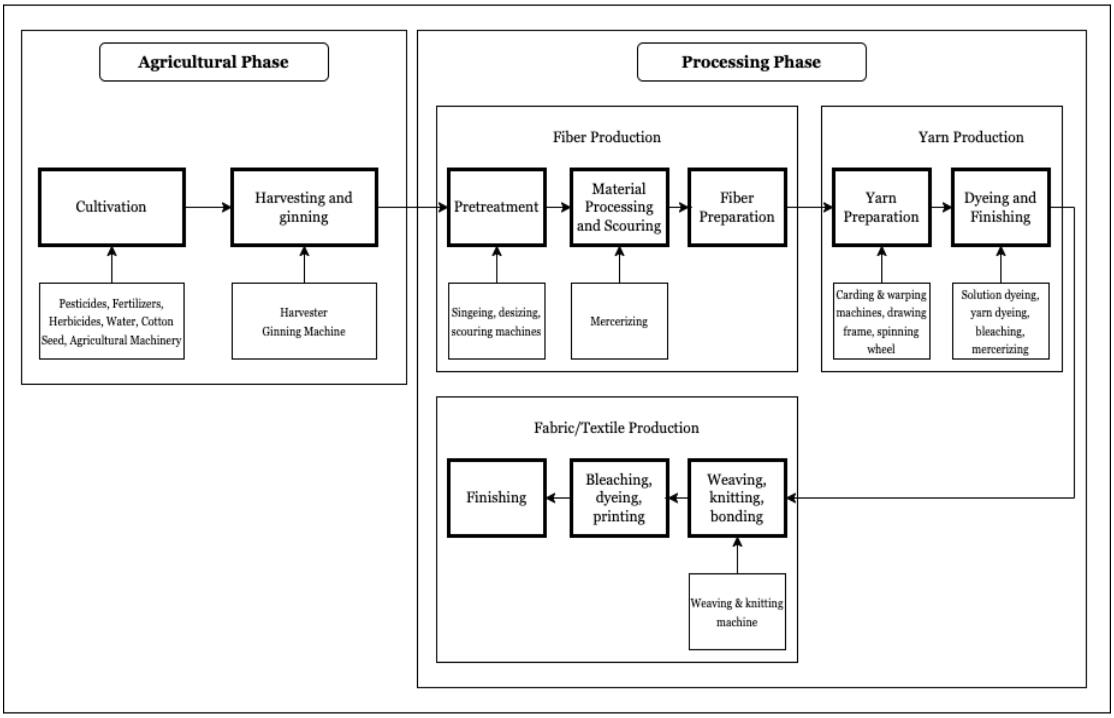

Figure 11 **Cotton and textile value chain**

Sources: Own illustration based on Bevilacqua et al., 2014; Halog & Abbas, 2021; Gürses et al., 2021

The cotton and textile industry encompasses all production processes - from the cultivation of raw materials (mainly cotton) to the manufacture of yarns, fabrics, filament yarns and fibers, and the production of ready-made garments (Egypt Business Directory, 2023). The value chain starts with the agricultural phase which includes cotton cultivation, harvesting and ginning. Various raw materials are needed for cotton cultivation, including cotton seeds, pesticides, fertilizers, herbicides and water. In addition, various agricultural machinery, such as picking machines, blenders and openers, are needed for this purpose (Bevilacqua et al., 2014).

The production phase is divided into the three phases fiber production, yarn and fabric production and textile production. The fiber production includes three steps which contain the extraction and processing of fibers. The yarn and fabric production includes the spinning of yarn and fibers. Different spinning techniques can be used here for example wet spinning and cotton spinning. In a further step, the yarn is further processed into fabrics by knitting and weaving. The wet processing phase in textile production includes pretreatment, bleaching, dyeing of the fabrics as well as the fabric finishing. The assembly process includes the cutting and sewing of the fabric into apparel products (Halog & Abbas, 2021). In order to identify relevant stakeholders, a stakeholder map has been developed. This stakeholder map can be found in the appendix.

4.1 Environmental hot spots

The production of Egyptian cotton and textiles has a large environmental footprint. This section describes the environmental hot spots along the cotton and textile supply chain in the agricultural and processing phase. For the identification of hot spots, the selected steps of the value chain were evaluated against the criteria, resource use (including water and material use) and climate impacts (mostly concerning greenhouse gas emissions). While it is considered necessary to disaggregate the processing phase in the three steps 1. fiber production, 2. yarn and fabric production, 3. textile production for analytical reasons, it should be mentioned that data was difficult to find for each step separately. This lack of data especially influences the weighting of the different steps.

4.1.1. Agricultural phase

In the agricultural phase, cotton cultivation leaches the soil, requires agrochemicals and is very water intensive, together accounting for its large environmental footprint. Experts highlighted in the interviews the pivotal role of the agriculture sector. Its growth trajectory significantly impacts the entire textile industry, making it imperative to direct attention toward this realm (EI – C, 2023).

Resource use

Farming practices

Egyptian cotton is usually hand-picked to avoid mixing the yields of mature and immature plants. Especially with hand-picked cotton, contamination of the lint by non-vegetable matter is one of the biggest problems (Gallico, 2020).

Experts underscore the importance of proper harvesting to minimize contamination and maintain the value of cotton fiber (EI - C, 2023). Impurities from soil and foreign matter during harvesting can compromise the subsequent spinning and textile quality. Ginning, a critical step where fibers are separated from seeds and debris, greatly influences the final product's quality. However, the process can also introduce new contaminants, underlining the need for skilled operation and training (EI - C, 2023). To address these issues, the Egyptian government has updated ginning machines, showing significant improvement ((EI – C, 2023). Furthermore, certifications like BCI, GOTS, and UNIDO have been instrumental in reducing contamination through organic training practices (ICAC, 2020).

Agrochemicals

Cotton cultivation is known for its heavy reliance on herbicides. Experts highlighted the extensive use of these chemicals in the conducted interviews (EI - C, 2023). Globally, cotton farming is a major consumer of insecticides and pesticides, using 24% and 11% respectively, despite occupying just 3% of arable land (Drew & Yehounme, 2017). The environmental impact is significant, with cotton plantations contributing over 3 tonnes of CO_2e per hectare to the global carbon footprint (EJF, 2020). Faced with declining cotton prices, farmers increase yield by intensifying the use of agrochemicals. Notably, cotton represents 5.7% of the $58.5 billion pesticide market and claims substantial shares of insecticide, herbicide and desiccant sales (EJF, 2020). 4% of the world's synthetic nitrogen and phosphorus fertilizers are used in the cotton production. However, the heavy application of these fertilizers, often referred to as "ecological narcotics", does not proportionally increase yields, but rather creates a dependency that can lead to reduced soil quality and lower crop production (EJF, 2020).

The loss of biodiversity is exacerbated by the aggressive use of chemical pesticides and fertilizers in farming. Land conversion for crop cultivation often entails the removal of native vegetation and habitats, thereby directly and adversely affecting biodiversity by disrupting essential ecological processes such as breeding and migration (Better cotton, n.d.)

Land use

Cotton thrives in arid regions due to its drought resistance but requires some humidity during its growth for optimal flower and boll development, as increased moisture during this phase enhances boll production (Sawan, 2017). However, excessive wetness during the ripening phase can degrade quality, with the plant favoring dry conditions (Bremer Baumwollbörse, 2022).

The high demands of cotton cultivation on water and land use impose high and growing environmental and opportunity costs on Egypt (Raza et al., 2020; EI - C, 2023). This includes the scarcity of water and arable land, an increasing import dependence on wheat, which is the country's main staple food and a rapidly growing population exerting demand pressures on food consumption, land requirements for settlements and infrastructure (Raza et al., 2020).

In the fertile Nile Delta, cotton's land use competes with food crops, with the added issue of pesticide runoff affecting soil and groundwater quality (Raza et al., 2020). Moreover, the prevalence of cotton monocultures contributes to soil erosion, due to intensive tilling and insufficient vegetative barriers.

Irrigation and water use

The water irrigation systems in Egypt are outdated and inefficient, suffering from a lack of investment, which leads to significant water losses through inefficient techniques like canal irrigation, marked by high levels of drainage and evaporation (Raza et al., 2020; Grumiller et al., 2020; EI – C, 2023). This inefficiency is particularly evident in the Nile Delta region, where cotton cultivation can consume up to 3,000 cubic meters of water per feddan (equal to 4,200 m^2, or 0.42 ha), underscoring the need for effective water resource management. There is already a government plan to convert the irrigation system to more efficient systems, for example drip irrigation (EI – C, 2023). The interviewed experts highlighted that surface irrigation is the predominant method for cotton cultivation, which is a water-intensive approach, contributing to Egypt's significant environmental costs (EI - C, 2023). This method of irrigation, in combination with cotton's overall water footprint - accounting for 3% of agriculture's 70% share of freshwater use - demonstrates the water-heavy nature of cotton production. A single cotton T-shirt can use about 2,700 liters of water, which is roughly the amount of water a person drinks in 2.5 years (European Parliamentary Research Service, 2020; Gözet & Wilts, 2022; Roberts, 2021).

Waste

Waste problems occur at several points in the value chain of the textile industry. This shows that a comprehensive change is necessary, away from the linear take-make-dispose model towards closed loops (Gözet & Wilts, 2022). According to the expert interviews, cotton waste from agriculture has potential impacts on various industries (EI – C, 2023). Cotton production waste includes various byproducts generated during the growing and processing of cotton, including leaves, stems and seeds. These wastes can be significant and present challenges for proper disposal. Cotton production wastes are not without value. In some cases, these byproducts can be reused for a variety of industries (EI - C, 2023).

Climate Impact

Resources

Conventional cotton farming is resource-intensive, consuming significant amounts of water, synthetic pesticides, and fertilizers, leading to environmental pollution. (EI - C, 2023). Specifically, the use of synthetic nitrogen and phosphorus fertilizers contributes to 1.2% of global greenhouse gas emissions. Inputs like ammonium nitrate further add to these emissions (EJF, 2020; Bevilacqua et al., 2014). Contrasting with agricultural food crops, climate change may paradoxically benefit cotton production in Egypt. Studies suggest a temperature rise could increase cotton productivity by up to 17%, with a 2°C increase and by about 31% with a 4°C increase (Fawaz & Soliman, 2017). However, the interviewed experts warns of climate change challenges such as irregular growing seasons, water scarcity, and the increased prevalence of pests and diseases, all of which necessitate adaptive strategies for sustainable cotton production (EI - C, 2023).

Machinery

Compared to other countries, there is limited use of agricultural machinery in Egypt. Still, if used, machinery in agriculture represents another environmental hot spot. A good (but outdated) overview on the resource use - mainly fossil fuels - of agricultural machinery such as picking machines, blenders and openers is offered by Bevilacqua et al. (2014).

Assessment criteria	Relevance	Explanation	Sources
Resource use	3	Agrochemicals (pesticides, insecticides, herbicides) pollute the soil and groundwater High water consumption due to ineffective irrigation systems; lack of investment and maintenance High land and water use, despite scarcity (cotton-food competition) Monoculture Contamination of the lint by non-vegetable matter through hand-picking Soil erosion caused by various factors: frequent and intensive tillage; Lack of Ground Cover; Lack of Vegetative Barriers Cotton waste from agriculture has potential impacts on various industries; byproducts such as leaves, stems, seeds present challenges for proper disposal (however, reuse possible)	Raza et al., 2020; EI – C, 2023; Gallico, 2020; Grumiller et al., 2020; Roberts, 2021
Climate impact	3	Use of synthetic pesticides and fertilizers leads to environmental pollution High climate impact of ammonium nitrate Use of agricultural machinery impacts by the use of fossil fuels/ natural gas	EI – C, 2023; Bevilacqua, 2014

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
for an explanation see section 3.1.1.

Table 3 Agricultural phase HSA summary and relevance score

Source: Own illustration

4.1.2. Processing phase

Resource use

The textile industry's wet processing, including pretreatment, bleaching, dyeing, and finishing, is resource-heavy and a significant pollution source due to inefficient energy use and inadequate wastewater treatment (Grumiller et al., 2020). Bleaching aims to whiten cotton using agents like sodium hypochlorite and hydrogen peroxide but can produce toxic by-products (Gürses et al., 2021; Madhav et al., 2018). Mercerization strengthens and prepares cotton for dyeing, resulting in alkaline waste. Dyeing, essential for colorfast textiles, contributes to the high volume of hard-to-treat wastewater in the industry (Gürses et al., 2021).

Water use

A key environmental risk in wet processing (mainly dyeing, washing, printing, and fabric finishing, which involves mechanical and chemical treatment of fiber, yarn or fabric to improve its aesthetic value) in the textile industry is inadequate wastewater treatment. In an already stressed environmental context, the excessive unsustainable use of natural resources and the partial lack of wastewater treatment lead to further environmental distortions (Raza et al., 2020). Already at the stage of yarn production the use of water for softening and disposal processes and chemicals used during mercerization and bleaching processes causes a high environmental impact (Bevilacqua, 2014; EI – C, 2023).

Specifically, the dyeing process in the textile manufacturing phase is one of the largest producers of wastewater. The wastewater contains chemicals from wet processing. These chemicals are toxic and low in biodegradability (Roberts, 2021).

Waste

The textile industry in Egypt generates approximately 200,000 tons of waste annually, with challenges in waste management stemming from poor segregation practices and a lack of awareness among workers and recyclers (EI - C, 2023). One third of this waste is pure cotton, central to the textile and clothing industry, while another 20% is from cotton blends, which are harder to recycle (Swithmed, 2020). Notably, spinning waste from cotton is significant but often recycled back into production (Switchmed, 2022). Despite the absence of systematic recycling (EI - C, 2023), high-quality cotton waste is either exported or reused in various industries, though some low-grade waste is still incinerated or landfilled. Small and medium-sized enterprises particularly struggle with technical aspects of waste management (EI – C, 2023).

Climate Impact

Energy consumption

Electricity consumption accounts for 5% to 10% of total production costs in the textile industry (Raza et al., 2020) with the generation of electricity being mostly based on natural gas (EI – C, 2023). The most energy intensive stages in the textile value chain are those of wet processing, for which high temperatures are needed. Also, the spinning and weaving process consume high amounts of electrical energy (Roberts, 2021). According to the expert interviews, the dyeing process, in particular, requires significant amounts of natural gas or gasoline, and both weaving and knitting are also noted for their high electricity demand (EI - C, 2023). This estimation is shared by the interviewed experts, who states that there is high energy consumption in the fabric manufacturing phase within the textile production. In addition, electricity consumption is particularly high in spinning mills (EI – C, 2023).

Technology and Machinery

Raza et al. (2020) noted the use of outdated technologies in Egypt's textile sector, attributing this to SMEs' limited capacities and funding shortages, which hinders clean production and competitiveness (Roberts, 2021). These outdated practices likely result in higher GHG emissions, contributing to climate impact, given that modern machinery tends to be more energy efficient. However, one interview partner counters this view, stating that the industry largely uses modern Italian and Swiss machinery, suggesting a lower climate impact. Cost factors and buyer preferences are also major forces driving technological updates in the sector (EI – C, 2023).

GHG-Emissions

The fashion sector accounts for 8.1% of global climate impacts (EJF, 2020). Producing textiles is energy-demanding, with one tonne yielding 15 to 35 tonnes of CO_2e, notably higher than plastic and paper (ibid.). The interviewed experts reports that 1kg of processed cotton releases 5 to 10 kg of CO_2 emissions across its value chain (EI - C, 2023).

Knowledge: Important Factor in the Agricultural and Processing Phase

The interviewed experts state that there are barriers to implementing greening options including the small size of cotton farms and the subsidization of many chemical inputs such as fertilizers and other inputs. In addition, there is a lack of information and knowledge about the economic feasibility and technical practicability of several greening options (EI – C, 2023).

Overall, human resources and a lack of skilled labor poses a challenge for green growth (Gallico, 2019). According to the interviewed experts there is a notable lack of worker knowledge, which combined with inflation challenges leads the workers to seek more profitable but riskier opportunities. The shortage of qualified workers is a persistent issue (EI - C, 2023).

This table first gives a general overview of the relevant criteria for resource use and climate impact in the processing phase. Then, secondly, it provides a specific overview within three relevant steps in processing: fiber production, yarn production, and textile/fabric production.

Assessment criteria	Relevance	Explanation	Sources
Relevant in all Processing Steps			
Resource use	3	High water consumption and wastewater production: The dyeing and printing process generates large quantities of wastewater, which contains large amounts of colorants, residual reactive dye, complex components, and binders that are difficult to degrade The textile industry generates around 200,000 tons of waste annually. Waste management faces challenges due to inadequate segregation in factories. Even with segregated waste, it is difficult to find suitable buyers due to a lack of awareness and training among both factory workers and recyclers in Egypt. More than a 1/3 of the total waste generated in Egypt is composed of 100% Cotton (which is aligned with the cotton centric T&C industry) Lack of information and knowledge about the economic feasibility and technical practicability of several greening options; Lack of skilled labor High energy consumption of machinery: One kilogram of a finished cotton product emits between 5 and 10 kilograms of CO_2-Emissions throughout the value chain Use of outdated machinery in all production steps	Gürses et al., 2021; Raza et al., 2020; Bevilacqua, 2014 EI – C, 2023 Switchmed, 2022 Grumiller et al., 2020; EI - C, 2023; Gallico, 2019 EI – C, 2023 Raza et al., 2020
Climate impact	3	One kilogram of a finished cotton product emits between 5 and 10 kilograms of CO_2-Emissions throughout the value chain The most energy intensive stages (mostly electrical/based on natural gas) in the textile value chain are those of wet processing	Raza et al., 2020; Roberts, 2021; EI - C, 2023

Mainly Relevant in Fiber Production			
Resource use	2	Mercerizing is an alkaline process for cotton fabric and yarn that increases the strength and dyeability of the fabric or yarn. The process can produce highly alkaline effluents including surfactant and suspended solids as NaOH is the main chemical	Gürses et al., 2021
Climate Impact	2	Machines used for singeging, desizing, scouring and mercersing	
Mainly Relevant in Yarn Production			
Resource use	2	High production of toxic wastewater with poorly biodegradable chemicals and high water consumption esp. in dyeing and bleaching processes Spinning waste (11%) amounts for 11% of the total textile industries waste in Egypt due to the omnipresence of cotton at the spinning stage, which is more waste-intensive than other fibers (i.e synthetics). Bleaching usually involves the use of one of the four main bleaching agents: Sodium hypochlorite, calcium hypochlorite, sodium chloride and hydrogen peroxide. The main problem of the bleaching process is the formation of highly toxic chlorinated organic by-products	Roberts, 2021; Raza et al., 2020; Bevilacqua, 2014 Switchmed, 2022 Gürses et al., 2021 Madhav et al., 2018
Climate impact	3	High energy consumption (mostly electrical/based on natural gas): 34% in spinning Energy for machines used in carding, warping, drawing and spinning High energy demand for the spinning and dyeing process - natural gas or gasoline	Ceeba, 2021; Raza et al., 2020; Roberts, 202; EI - C, 2023

Mainly Relevant in Fabric & Textile Production			
Resource use	2	High production of toxic wastewater with poorly biodegradable chemicals and high water consumption esp. in dyeing and bleaching processes Based on the industry split between weaving and knitting mills, it is estimated that every year 20 Ktons of knit waste and 36 Ktons of weaving waste are generated, together amounting to 26% of the total waste mix in Egypt. Mercerizing is an alkaline process for cotton fabric and yarn that increases the strength and dyeability of the fabric or yarn. The process can produce highly alkaline effluents including surfactant and suspended solids as NaOH is the main chemical Around 20 tonnes of knitting waste and 36 tonnes of weaving waste are produced each year High energy demand for the dyeing and weaving and knitting processes - natural gas or gasolin	Roberts, 2021; Bevilacqua, 2014 Switchmed, 2022 Gürses et al., 2021 Switchmed, 2022 EI – C, 2023
Climate impact	3	High energy consumption in wet processing, 23% in weaving, 38% in wet processing (incl. applies also to yarn production), 5% for miscellaneous	Ceeba, 2021

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, 0 = no data for an explanation see section 3.1.1.

Table 4 Processing Phase HSA summary and relevance score

Source: Own illustration

4.2. Results of hot spot assessment

The fact-based research on each of the focus stages of the value chain identified the biggest environmental problems in terms of resource use in the agricultural phase, while considering the Climate impact the agricultural and the Processing phase have major impacts.

Table 5 gives an overview of the identified relevance of each step of the cotton value chain.

Identification of Hot Spots

Lifecycle Category	Agricultural Phase	Fiber Production	Yarn and Fabric Production	Textile Production
Resource use	3	2	2	2
Climate impact	3	2	3	3

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, 0 = no data
for an explanation see section 3.1.1.

Table 5 Hot spots in the cotton value chain

Source: Own illustration

From the identified relevance of the individual stages in a final step the hot spots are identified. For a better visibility of the hot spots, the relevance of both factors resource use and climate impact are multiplied by each other.

Agriculture: Resource Use 3 * Climate Impact 3 = Total 9

Processing:

Fiber Production Resource Use 2* Climate Impact 2 = Total 4

Yarn and Fabric Production Resource Use 2* Climate Impact 3 = Total 6

Textile Production Resource Use 2* Climate Impact 3= Total 6

	Agricultural Phase	Fiber Production	Yarn and Fabric Production	Textile Production
Weighting	9	4	6	6

low relevance = 1 to 9 = highest relevance

Table 6 Weighting of the lifecycle phases

Source: Own illustration

4.3. Greening options and focus group evaluation

Greening options address a variety of causes for resource (over-)consumption and aim to avoid the environmental impacts of cotton and textile production. For example, lower water and energy consumption in the processing of textiles and recycling of textile waste are central to the greening of the textile industry (EI – C, 2023).

In addition to the greening options that were proposed by the project team, new greening options were added by the stakeholders participating in the expert interview and focus group discussions (FDG – C, 2023). The focus group participants then selected eight greening options and evaluated them against a set of criteria and categorized strengths and weaknesses (see methodology chapter 3.1.3.)

The discussed greening options are described below. Similar proposed greening are described integrated. Identified greening options that were not selected for a deeper discussion in the focus group are presented afterwards.

Enhancing circularity in the textile industry: waste streams are minimized – waste fed back into production

The textile industry's shift from a "take-make-dispose" model to a circular economy is crucial for minimizing waste and reusing materials (Gözet & Wilts, 2022). Egypt's textile sector, with its significant waste, could benefit from circular practices by improving efficiency and environmental outcomes (Raza et al., 2020; Rezek, 2023; FGD - C, 2023). **Textile-to-textile recycling**, particularly in the spinning industry, has potential but needs investment and better waste segregation (FGD - C, 2023). A lack of education and waste valuation, plus the high costs of necessary technology for sorting, hinder progress, with only one small factory currently recycling (EI – C, 2023). However, discussions in the focus group emphasized the promotion of **new job opportunities** and potentially increasing the number of factories. Nonetheless, challenges arise from the **high technology and access costs**, as well as capital investment requirements and design constraints. In terms of climate impact, the promotion of textile-to-textile recycling contributes to pollution reduction, lower carbon emissions, and decreased energy consumption. Moreover, it aids in the conservation of virgin resources and actively promotes reuse and circular economy principles. From a social perspective, this initiative offers the potential for increased employment and income opportunities (FGD - C, 2023).

In the agricultural phase, **cotton processing byproducts** like linters, used in the paper industry, and cottonseed oil, extracted from seeds, can be recycled (Rahman & Uddin, 2022; Harwood et al., 2017; Sharif et al., 2019). During processing, chemical, mechanical, and biological recycling methods are proposed to close production loops (EI – C, 2023; Ribul et al., 2021). Although recycled cotton's market share as only about 1% in 2021; it's increasing, with waste cotton being utilized for yarn production. Cotton stalks serve the paper industry, while seeds yield edible oil (EI - C, 2023). Additionally, carboxymethylcellulose (CMC) has been successfully derived from cotton waste, offering an eco-friendly waste treatment solution (Bahlool & Kamel, 2023). Synthetic waste finds potential use in Egypt's carpet and home textile sectors (EI – C, 2023). Nevertheless, the focus group discussed concerns about potential effects on product quality are duly noted. On a social note, the initiative has the potential to **generate job opportunities**, marking a positive step forward in the industry's impact on employment (FGD - C, 2023).

UNIDO's pilot project on cotton blend yarn from recycled materials found it less costly and more energy-efficient than virgin yarn, reducing new cotton fiber procurement (Roberts, 2021). This recycled yarn also consumes less water, as it diminishes the need to grow new cotton plants. Life Cycle Assessments indicate that regenerated cotton yarn could better minimize global warming potential by lessening the need for crop cultivation and energy consumption. Although blending yarn is more resource-efficient, potential savings in Egypt are limited by the country's fossil fuel-dependent electricity grid. This dependence results in rebound effects, where any efficiency gains in the production process are offset by the high carbon footprint of the energy source. Essentially, while the production becomes more efficient, the overall environmental impact is not significantly reduced due to the reliance on fossil fuels for electricity generation (UNIDO, 2020).

Reuse of agricultural waste in manufacturing (leaves, stems and seeds)

Key points emerging from the focus group discussions underscored the potential for **reusing agricultural waste**, including leaves, stems and seeds. For the private sector and SMEs, this approach offers the opportunity to save costs and provides an additional source of income with relatively low capital investment. However, challenges arise concerning **limited access to technology**, as well as the availability of funds for micro, small, and medium-sized enterprises (MSMEs), and the development of an effective waste collection plan. Regarding the climate impact, the reuse of agricultural waste contributes to waste and carbon emission reduction, offering the opportunity to tap into other industries and benefit from the resulting value chain. The resource impact is evident, as this approach enables resource conservation and leverages low-energy technology, while also creating energy by-products such as compost. Despite these advantages, some of the technologies employed can be energy-intensive. From a social perspective, the reuse of agricultural waste presents the opportunity for enhanced training access, fostering gender equity through increased participation. It also serves to increase income and provides products that help address various challenges faced by farmers, including rising prices. However, challenges persist, including limited awareness, low levels of education, and the operational burden associated with implementing these strategies (FGD - C, 2023).

Education and training in sustainable agricultural technologies and practices

As discussed in the focus group, education and training in sustainable agriculture can significantly **strengthen sustainable agricultural practices and crop productivity**. This heightened production efficiency not only aids startups and SMEs in implementation but also amplifies opportunities for increased exports. Moreover, the establishment of small recycling companies demonstrates a tangible commitment to sustainability. However, these efforts are hindered by **long-term investment requirements**, funding constraints, and the persistent challenge of balancing production demands with educational needs. On a positive note, the climate impact of these initiatives is evident in the **reduction of pesticide use and a lighter environmental footprint** during harvesting and irrigation. Additionally, the resource impact is advantageous, characterized by resource conservation and increased yield per acre. Despite these strengths, social impacts encounter resistance and economic pressures, occasionally leading to rejection from small-scale farmers (FGD - C, 2023).

Renewable Energy Utilization and Efficiency: Solar Photovoltaics and ISO 50001 Energy Management

In the focus group, the use of renewable energy, particularly solar energy, and the implementation of Energy Efficiency ISO 50001 were highlighted due to its broad utilization in Europe and for reasons of **market standardization** (Roberts, 2021). For the private sector and SMEs, the idea of **long-term cost savings** sounded promising, but the initial costs, the current **insufficient amount of energy available and the lack of available funds** for installing solar equipment emerged as significant hurdles that require long term investment and government support. Regarding its climate impact, the intelligent utilization of solar-based energy leads to reduced emissions, relying on a renewable energy source, resulting in a decrease in carbon emissions. Looking at resources, the initiative exhibits potential in decreasing reliance on depleting resources. On a social level, it fosters job creation within the solar energy business sector, although challenges exist, including **limited awareness** of solar energy benefits and insufficient collaboration between research and development and the industry (FGD - C, 2023).

Alternative agricultural inputs (e.g. biofertilizer, biopesticides)

Discussions in the focus group highlighted the potential of alternative agricultural inputs, such as biofertilizers and biopesticides. These alternatives offer the strength of reducing or eliminating the use of chemical fertilizers, thereby **cutting production costs** and opening **new doors for export opportunities**. However, challenges arise from the higher initial costs, limited access to technology, and the potential difficulty in competing within the local market. In terms of climate impact, the utilization of these alternative inputs aids in maintaining environmental equilibrium and obtaining bioproducts. Moreover, they contribute to the **conservation of vital natural resources like water and soil**, while mitigating pollution to **preserve the ecological balance** in the environment and reduce production costs. The resource impact is notable, improving the overall characteristics of agricultural land and safeguarding the natural resources and environmental balance. On the social front, these alternatives show promise in **enhancing health and safety standards, raising awareness, and safeguarding the wellbeing and livelihoods of farmers.** This is accomplished through the maintenance of farms and the reduction of diseases resulting from pesticide residues. Despite these advantages, challenges persist in the form of limited awareness and understanding of the importance of these alternative inputs (FGD - C, 2023).

Water management – implementation of water recycling or treatment measures (minimizing water consumption and water waste)

According to the conducted expert interviews, an implementation of water recycling or treatment measures as well as the minimizing of water consumption and water waste in the dyeing phase can enhance the value chain (EI - C,2023). The two inputs, water and the use of chemicals in wet processing are inextricably linked. In order to reuse water and reduce water consumption, there needs to be knowledge transfer and coaching on zero-hazard chemical usage, for example also via the ZDHC (Zero Discharge of Hazardous Chemicals) certificate (EI – C, 2023).

During the focus group discussions on water management, the spotlight was on adopting water recycling and treatment measures to minimize water consumption and reduce wastage. For SMEs and the private sector, the potential for increased exports and **significant cost savings** emerged as the key advantages. In terms of its impact on the climate, the initiative shines in its ability to reduce the carbon footprint and lower the consumption of water sources. However, the **absence of laboratories and certification bodies** in Egypt posed notable challenges. Regarding resources, the greening option showcased its potential for cost savings and a noticeable reduction in water usage within the industry. Although, the persistent **lack of funding for water treatment tools** remains a significant hurdle. On a social level, the initiative contributes to the reduction of water consumption, underscoring a positive step toward more sustainable water management practices (FGD - C, 2023).

Environmental certification

Certified sustainable production practices under the BCI and similar initiatives can scale up market access to the EU as well as to other markets (Raza et al., 2020). Certifications, such as those under the BCI, GOTS and UNIDO’s FILMAR schemes (Gallico, 2019; ICAC, 2020) as well as resource efficient practices can also increase resource efficiency and reduce energy and other inputs. Certifications are thus not only important to ensure compliance with **international environmental regulations** but also with regards to their potential benefits in reducing resource consumption and enhancing the competitiveness of SMEs in local production. Despite its associated extra costs, certification represents an opportunity to access **added value, expertise, and knowledge**, which can be utilized to improve cost management (FGD - C, 2023). Buyers and consumers increasingly demand transparency of business procedures, supply chains and traceability of products. Projects are required that can build upon the most successful traceability practices already in place, for example the Cotton for Life Program and Filmar’s NILO production (Gallico, 2019). In the focus group discussion on environmental certification, the focus was on assessing its feasibility for the private sector and SMEs. For businesses, the advantages were evident in the increased export **opportunities for factories and heightened competitiveness of local products**. However, challenges were highlighted, including the high cost of training for certification implementation and the need to raise awareness among SMEs about the environmental requirements necessary for exporting their products. Regarding the climate impact, the certification process played a crucial role in **fostering environmental responsibility** awareness and enhancing productivity efficiency. It also emphasized the importance of compliance with international environmental regulations, leading to positive implications for Egypt’s industrial sector. However, some resource-related challenges emerged, such as the absence of a local certification body for CO_2 and the limited number of certification bodies specializing in the environmental field. On the social front, the certification process demonstrated its potential in **increasing income** through compliance and improving the understanding of environmental impacts for the stakeholders involved (FGD - C, 2023).

Further greening options that were not discussed within the focus group are discussed below.

Cultivation of higher-yielding varieties

The aim of cotton breeders is to develop better cotton plants with **good fiber quality** characteristics. Cotton improvement targets yield and yield components such as number of kernels, boll size and number of bolls per plant, seeds per boll, seed size, lint index, seed index and ginning result (Abdel-Aty et al., 2022; EI - C, 2023). For example, yield increases are attributed mainly to the cultivation of higher-yielding varieties and/or the use of better agronomic practices (El-Marsafawy et al., 2018). In addition, identifying and introducing modern farming practices, such as less chemical use, saving water and using organic growing methods, among cotton cultivators is of paramount importance (EI - C, 2023).

Land and water use

Effective water resource management in cotton production is highly important. Currently, there is a focus on an irrigation method that involves **optimizing water usage**. The approach is to extend the duration of water application while reducing the total amount of water used. This strategy aims to improve water efficiency, mitigate water scarcity issues and contribute to more sustainable cotton growing practices (EI - C, 2023).

Above that, the interviewed experts mentioned that adopting sustainable practices such as using **treated wastewater for irrigation** can be a viable solution to significantly reduce water consumption (FGD - C, 2023). This approach not only conserves water resources, but also contributes to more efficient and responsible cotton farming (EI – C, 2023).

Additionally, according to the expert interviews **research and developmen**t are crucial: A cotton plant variety has been bred, whose life has been shortened by 60-70 days, leading to a reduced irrigation period by 1.200 liters of water. This reduction aligns with the decreased use of various chemicals. As pesticides contribute to soil and groundwater pollution, another possibility is to **shift cotton cultivation to less fertile soils** in order to be able to use the fertile soils for growing food (Raza et al., 2020).

Drip irrigation

Around 2.5 million cubic meters of water could be saved per year if water consumption in the entire textile sector was reduced by 1% (Roberts, 2021). According to expert interviews a possibility to reduce the water consumption in cultivation is to shift to drip irrigation, an option which also helps to save production costs (EI - C, 2023). According to the expert interviews, drip irrigation is a method that **fits well with modern and extensive farming methods**. Drip irrigation, which features targeted water delivery directly to plant roots, enables efficient water use and resource conservation, making it an attractive option for large-scale and technologically advanced cotton farms (EI – C, 2023).

Organic cotton

Due to changing demand patterns as well as the trend towards sustainability, opportunities exist for environmentally friendly cotton and textile production (Raza et al., 2020). However, organic cotton production is limited in Egypt (Raza et al., 2020). It currently represents a very minor percentage of the total cotton production in Egypt (Gallico, 2019). Promoting the cultivation of organic cotton has a positive impact on the achievement of the UN Sustainable Development Goals (SDGs), as it has a significantly **lower ecological footprint and soil quality is usually preserved** (Raza et al., 2020). Significantly lower amounts of blue water (up to 80%) is needed for organic cotton production (Raza et al., 2020).

In May 2020 Egypt became a member country of the Better Cotton Initiative Programme, with the aim of increasing sustainability and improving conditions for Egyptian cotton farmers. Based on the Better Cotton Principles and Criteria, participating farmers receive training. By following these principles, farmers produce cotton that is **better for the environment and farming communities** (UNIDO, 2021). Our interview partners agreed that the promotion of organic cotton cultivation and educational programs for its implementation are imperative for greening the cotton and textile industry in Egypt (EI – C, 2023). Experts pointed out in the interviews that in Egypt around 90% of organic cotton production is from organizations like Sekem for instance. They stand out as key players capable of producing organic cotton with exceptionally high standards (EI - C, 2023).

Agroforestry

Expanding forest cover while **preserving traditional cotton cultivation** can be effectively achieved through agroforestry. The Apulia Regenerative Cotton Project, a collaborative effort involving the European Forest Institute (EFI), the Council for Agricultural Research and Economics of Italy (CREA), and PRETATERRA, aims to pioneer a project in Italy whose primary objective is to establish an experimental agroforestry site for regenerative cotton. Its purpose is to explore and scientifically evaluate novel approaches to sustainable cotton production. The overarching goal is to showcase how landscape diversity, water conservation, soil fertility improvement, and biodiversity-related ecosystem services can be enhanced while concurrently achieving low carbon emission in cotton production through the utilization of agroforestry systems (EFI, 2023).

By **incorporating indigenous trees** into cotton landscapes, the agricultural system gains multiple benefits, including ecological and environmental services such as biodiversity conservation and carbon sequestration. Additionally, it helps prevent soil erosion and enhances soil fertility. These trees also serve as a **valuable resource for local communities**, providing wood for fuel, fruits, and an additional source of income, all without negatively affecting the growth of cotton and other crops. Ecosystem services, such as soil fertility, natural pest control, and pollination, play essential roles in cotton crop production. Simultaneously, conserving genetic diversity contributes to the resilience of agricultural systems. It is crucial to foster sustainable solutions within farming communities to promote biodiversity conservation and minimize adverse impacts on the natural environment (WWF & IKEA, n.d.)

Implementing **regenerative practices** like cover crops and nitrogen-fixing trees can mitigate land and soil degradation, nutrient depletion, and reduce the reliance on synthetic fertilizers. Such approaches not only improve soil health but also bolster farming resilience in the face of changing weather patterns. Additionally, regenerative farming aids in carbon sequestration and uplifts the livelihoods of smallholder farmers. In the Kenyan Renature model farm, for example, thousands of farmers are trained in regenerative techniques to intercrop trees and herbs, such as moringa, onions, garlic and basil (reNature, n.d.).

Furthermore, in a Chinese project, the **intercropping** of Jujube and cotton **in an agroforestry system** highlighted the positive link between microclimate and yield. This intercropping not only protects the cotton's growth environment but also boosts farmers' income by enhancing the field microclimate. Additionally, the successful intercropping of peanuts and cotton has increased productivity and economic gains while regulating plant nutrient accumulation and fostering a healthy soil microbial community (reNature, n.d.; Wang et al., 2022).

Intercropping/crop rotation

Intercropping and crop rotation are pivotal in bolstering crop productivity and ecological advantages. Intercropping (simultaneously cultivating multiple crops in the same space) cotton with maize or vegetables, despite slightly reducing cotton yield, boosts overall productivity and farm income, with maize-cotton intercropping yielding 80.45% of pure cotton and an additional 2.17 tonnes of maize (Metwally et al., 2012). Intercropping **cotton with vegetables** can lead to a 30-40% increase in farm income. Additionally, alternate intercropping patterns can further increase yield by 17-21% and land efficiency by 20% (Lv et al., 2023). It also alters the root zone microecology and canopy microclimate, affecting plant structure and yield (Lv et al., 2023).

Conversely, **crop rotation**, which involves growing different crops in succession to **improve soil fertility** and balance nutrients, is especially beneficial when organic cotton is included in the sequence. This practice not only **conserves water** but also increases profitability, influencing the adoption of cotton-based crop rotations (Quda & Zohry, 2015; Eyhorn et al., 2005; Lv et al., 2023). Crop rotation enhances the soil's organic matter and nutrient content, offering a sustainable farming approach (Lv et al., 2023).

Machinery & technology

Advancements in Egyptian cotton machinery not only enhance the quality of cotton products but also contribute to waste reduction (EI - C, 2023). **Modern technology** optimizes the **removal of impurities** from fibers, leading to cleaner, high-quality cotton. The improved efficiency in cleaning, drying, and processing **minimizes waste**, ensuring the production of pure, environmentally-friendly cotton that aligns with customer demands for quality and sustainability (EI - C, 2023).

Regarding **spinning efficiency**, a notable feature is the **deployment of two generators**—one for low-energy generation and the other for high-energy generation. This transition between generators exemplifies an energy-efficient approach (EI – C, 2023).

Energy

Solar energy offers long-term greening potential for Egypt's textile industry, with photovoltaics increasingly viable as electricity subsidies decrease and competitiveness with grid electricity improves. **Government support** could make solar energy a cost-saving measure for SMEs (EI - C, 2023). Textile production, particularly spinning and yarn production, is energy-intensive, consuming up to 40% of the sectors' energy - mainly electricity - and weaving predominantly using natural gas (EI – C, 2023). Transitioning to renewable electricity, including solar, for industrial operations like heat generation could optimize energy use, as suggested by the interviewed experts (EI - C, 2023).

Supply chain collaboration and coordination

It became clear that **government support** is needed to enable supply chain collaboration and coordination. Especially in first, the case of ecological farming practices and second, in that of circularity government support is valued: First, linked to intercropping of food and fiber and their respective chains it became clear, that the relations between farmers for food and leading companies in the Egyptian organic and fairtrade cotton chains are another relevant field for a social-ecological transformation and a greener economy (Rota et al., 2018). Second, there is a need for government investments in the education of staff and management ensuring **knowledge on circularity** and for the **facilitation of networks and collaboration** between manufacturers, waste collectors and re-manufacturers (EI – C, 2023).

Particularly important, therefore, is a focus on supply chain collaboration, which Cao and Zhang (2010) define as "a partnership process where two or more autonomous firms work closely to plan and execute supply chain operations towards common goals and mutual benefits", and can help foster green and socially responsible transformation. A prerequisite for collaboration along the supply chain is the promotion of **transformational leadership**. Transformational leadership is the co-creation of collaborative supply chain management and can be understood in contrast to buyer-driven or supply chains in which the value-capture is directed predominantly toward the lead company. Adopting such new procurement thinking, suppliers, sustainability initiatives and (lead) firms along the chain participate in the process, exchange views and work together.

Another area in which coordination and networking needs to be facilitated is in the **coordination of waste management and recycling and the operationalization of circularity** amongst different partners in Egypts cotton and textile industry (EI – C, 2023).

Literacy and sustainability by design

According to the interviewed interviews, **technology awareness among farmers** plays an important role (EI – C, 2023). By providing education and training in **modern agricultural technologies and practices**, farmers would be able optimize their productivity and resource utilization. According to Roberts (2021) and the conducted expert interviews the private sector is very active in manufacturing, but there is a severe lack of skilled labor and a lack of **awareness of global trends**. Small and medium enterprises in particular need support in implementing a green economy. They need support in raising awareness, receiving coaching (e.g. in lean manufacturing) **showcasing green economy alternatives** compared to current and conventional practices, which represents a feasible and relatively short-term greening option (EI – C, 2023).

According to the interviewed experts the promotion of **training initiatives for employees and workers** in collaboration with government agencies and vocational schools that have significant human resources has, in the long term, the potential to improve the quality of work and lead to significant growth in the labor market (EI - C, 2023).

It is also crucial to improve the **sustainable design capacities of SMEs** (sustainable industrial design, textile engineering) in order to promote functional upgrading and to benefit from trends in the EU market. Therefore, business training and internships for design students should be systematically included in the curricula of design schools and university programmes. To this end, **cooperation with EU-based design schools** should be used for student exchanges and internships of Egyptian students in EU companies. In addition, the Egyptian government should provide incentives for textile companies to establish career development programs for young workers to improve their skills in sustainable industrial design, textile engineering, etc. (Grumiller et al., 2020).

5. Sugar beet value chain

Sugar is a sweet-tasting, crystalline food product that is obtained from both sugar cane and sugar beet and consists mainly of sucrose. This report focuses on the production of refined sugar from sugar beet. It includes the agricultural phase of cultivating sugar beet, followed by the processing phase, which includes the steps of preparation, juicing, thickening, refining and results in the final product, white sugar. In the distribution phase, the sugar is transported to wholesalers, from there to either retailers or industrial users and finally to the end consumer.

The **sugar beet value chain** considered in this report is divided into the agricultural phase, the processing phase and distribution phase. An overview and visual representation of these steps is given in Figure 12.

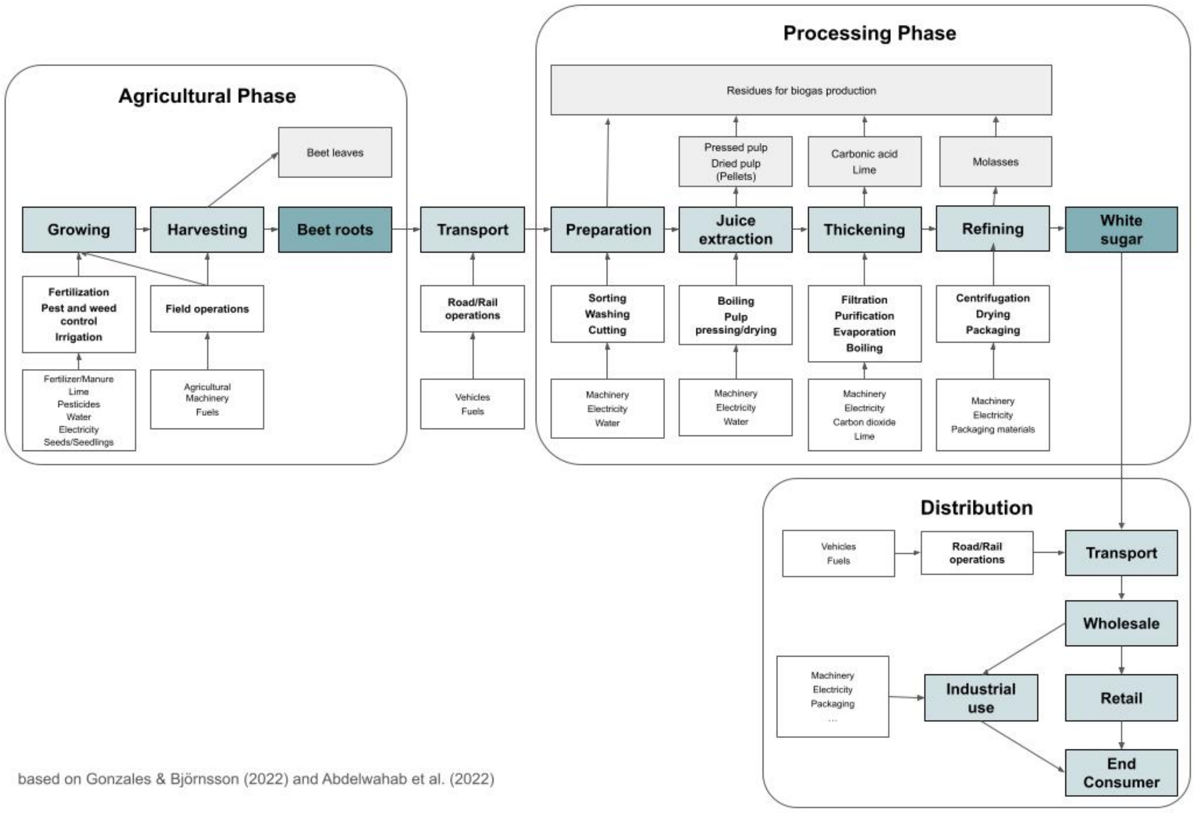

Figure 12 Flow chart of the sugar beet value chain

Sources: Own illustration based on Gonzales & Björnsson, 2022; Abdelwahab et al., 2022

The agricultural phase consists of the growing and the harvesting of the sugar beet. Growing involves fertilization, pest and weed control and irrigation. Required inputs are fertilizer, lime, pesticides, water, electricity, seeds and seedlings. Harvesting involves field operations requiring farm machinery, fuel and electricity. Transport between the agricultural and processing phase requires road and rail operations including the provision of vehicles and fuel. The processing phase consists of preparation, juice extraction, thickening, refining and results in the final product, white sugar. Preparation includes sorting, washing and cutting and requires machinery, electricity and water. To remove mud, stones, leaves and other impurities, the beet is directed into gutters. Sugar beet as a root crop requires a lot of cleaning, which produces a lot of waste water and a large amount of sludge is deposited (Cheesman, 2004). The same inputs are required for juice extraction, which involves boiling, pressing and drying the pulp. Extracting sucrose from beet is easier than from sugar cane because the beet can be stored longer after harvesting and the sucrose can diffuse easily in the cells of the beet. Beet is sliced and processed, yielding a juice with a higher degree of purity, whereas sugar cane must be shredded or crushed, washed and ground or diffused to extract juice, and bagasse is often used as a fuel source (Cheesman, 2004). By-products of the extraction process are pressed pulp and dried pulp (pellets). The next stage is thickening, which involves filtration, purification, evaporation and boiling. This requires machinery, electricity, carbon dioxide and lime. Clarification is the process of removing impurities from juice and adjusting its chemical properties using lime or other additives. Treated juice is passed through clarifiers to remove solids. The clarified juice is then concentrated using multi-effect evaporators, where the efficiency of the evaporator management is critical to the energy efficiency of the overall processing operation. Crystallization of sugar involves boiling the concentrated juice to form sucrose crystals, with impurities concentrated in the mother liquor; multiple boilings are done to maximize sucrose recovery. The process generates molasses as by-product. Beet juice allows for the production of white sugar directly at the beet factory or raw beet sugar, which is refined elsewhere (Cheesman et al., 2004). Generally, sugar beet thick juice is used for the production of sugar or ethanol and has two by-products: beet pulp, which is used in animal feed, and molasses, which can be further processed to extract crystal sugar, again producing molasses as a by-product (OECD & FAO, 2023).

Refining consists of centrifuging, drying and packaging and requires machinery, electricity and packaging materials. The by-product is molasses and the end product of the processing stage is white sugar. At all stages of the processing phase, organic residues are generated which can be used in a separate plant for the production of biogas.

In the final stage of distribution, the end product of the processing stage, white sugar, is transported to wholesalers, from there to either retailers or industrial users and finally to the end consumer. Transport between the agricultural and processing phase is considered together with the final phase of distribution of the value chain in terms of environmental hotspots.

In order to identify relevant stakeholders, a stakeholder map has been developed and can be found in the Annex.

5.1. Environmental hot spots

5.1.1. Agricultural phase

Resource use

Sufficient and efficient **irrigation** has a strong impact on the yield and quality of sugar beet and thus on the entire value chain. However, irrigation is also site-specific as the water holding capacity of soils can differ heavily. According to Elzayat et al. (2022), sugar beet in Egypt typically needs about 7-8 irrigation events or up to 15-20 irrigations in light sandy lands. The water footprint for sugar beet production in Egypt is relatively high, averaging 232 m^3 per tonne, compared to the global average of 132 m^3 per tonne (Ibrahim et al., 2021; Mekonnen et al., 2011). However, in this study the figures varied considerably between the different growing regions (New Valley has the highest total water footprint at 621,834 m^3/tonne, whereas the lowest total water footprint was found in Menia 143.6 m^3/tonne). Water management and irrigation practices are dependent on the growing region: In the Old Delta conventional agricultural practices and techniques are predominantly employed, namely flooding or surface irrigation. In the New Delta more efficient irrigation methods like drip irrigation or pivot irrigation are used (EI - S, 2023). Climate change in particular will further intensify the problem, as rising temperatures will increase the evaporation rate of irrigation - especially for surface and sprinkler irrigation - and more irrigation will be required in the future (EI - S, 2023). Finally, research indicates that current water supplies will not meet future demand. Population growth, industrialization, increased pollution and poor management of water resources are all contributing to this growing problem (Fishar, 2016; Fawaz et al., 2016; Fadl et al., 2020). With regard to sugar production, it is still worth noting that the production of one kilogram of sugar requires approximately 1.4 m^3 of water for sugar beet and 4.0 m^3 of water for sugar cane (Yassin et al., 2021), which finally makes sugar beet more water-efficient to cultivate.

The use of appropriate **fertilizers** plays a crucial role in the sugar beet value chain in Egypt and, in combination with efficient irrigation, can have a significant impact on the environmental footprint and the yield of sugar beet crops. Used appropriately, it can maintain soil fertility and prevent crop losses by controlling weed pests and disease outbreaks. However, excessive or incorrect application can also cause significant environmental damage, making proper application and accurate dosing even more important (Cheesman, 2004). Many of the experts interviewed stated that fertilizers and pesticides are used very intensively in Egypt (EI - S, 2023; FGD - S, 2023).

With regard to the use of Nitrogen-Potassium-Kalium fertilizers, it is also significant that phosphorus is a finite resource and will become scarce in the long term. Since the use of such fertilizers in agriculture is essential for production, it is even more important to recycle phosphorus so that the reserves of this non-substitutable nutrient are not exhausted (Dawson et al., 2011).

Erosion is a complex natural process influenced by several key factors, including soil composition, terrain characteristics, and climatic conditions, e.g. heavy winds. Crops that provide only partial or late-season coverage of the soil (such as sugar beet) increase the vulnerability to erosion. In such cases, wind and water can directly wear away the exposed soil, leading to erosion. Without supportive measures like intercropping, subsoiling, or mulch seeding, the soil is at a significantly higher risk of erosion. Furthermore, the intensity of soil cultivation practices is essential to consider (UBA, 2022; Bürcky, 2009). Especially the sugar beet harvest leaves the ground exposed and susceptible to erosion. The use of heavy harvesting machinery compacts the soil, diminishing habitats for soil organisms, causing harm to soil structures, and resulting in the loss of numerous organisms (GNF, 2018). However, this is not an issue for all fields, as (especially the small scale farmers) harvest manually, according to the Interviews.

Climate impact

There is limited literature on Life Cycle Assessments (LCAs) and the climate impacts of sugar production in Egypt. But a recent study by Gonzales et al. (2022) conducted in Sweden provides valuable insights into the greenhouse gas emissions associated with sugar production. The research found that a share of 44%, of total emissions in sugar production is attributed to crop cultivation. This share is attributable to various processes in cultivation: 1.536.85 kg CO_2e/ha·y57.5 % are released from biogenic soil emissions during sugar beet cultivation. These emissions are primarily related to the natural processes occurring in the soil. Fertilization (production and application) accounts for approximately 682.72 kg CO_2e/ha*y or 25,6%. Field operations, such as plowing and harvesting, contribute to emissions as well, amounting to about 438.18 kg CO_2e/ha*y or 16.4%. These emissions arise from the use of machinery and fossil fuel combustion. Pest and weed control measures result in emissions of around 1.47 kg CO_2e/ha*y or 0.1%.

Agriculture is one of the most energy-intensive sectors and highly dependent on fossil fuels. This includes field operations and tillage, production of seeds, harvesting, irrigation and especially the production of fertilizers. Similar to the study mentioned above El-Gafy et al. (2016) investigated that 25% of the emitted CO_2e is caused by the production and use of synthetic nitrogen fertilizers.

Assessment criteria	Relevance	Explanation	Sources
Resource use	3	Irrigation heavily affects productivity and quality. Water consumption for irrigation is relatively high (compared to global average) Fertilization use is vital for high yields, excessive or incorrect application can also cause significant environmental damage, P is a finite resource	Mekonnen et al. 2011; Ibrahim et al. 2021; Elzayat et al. 2022; Yassin et al. 2021
Climate impact	3	GHG emissions are released along the entire value chain, but particularly in the agricultural phase. They mainly result from biogenetic soil emissions by fertilization (CO_2 emissions from lime application, ammonia emissions, and direct and indirect N_2O emissions from nitrogen fertilization) and by energy use (e.g. production of fertilizers) as a major source of GHG emissions	El-Gafy et al. 2016; Calzadilla et al. 2013; Mehanna et al. 2017, 2020; Yassin et al. 2021; Gonzales et al 2022

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
for an explanation see section 3.1.1.

Table 7 Agriculture phase HSA summary & relevance score

Source: Own illustration

5.1.2. Processing phase

Resource Use

In the further processing of sugar beet into refined sugar, **water** utilization is particularly relevant for resource consumption. A large amount of water is needed in the cleaning process in order to remove the soil adhesion from the beet roots. Further, water is also essential in the further production stages of sugar extraction. Beside the cleaning of the beet water is also needed for the extraction, clarification and filtration (Cheesman et al., 2004). The wastewater from sugar processing in particular is a source of environmental pollution and, especially when products such as lime are used, the pollution of groundwater and surface water is considerable. Thus, wastewater treatment and waste management in the processing phase is essential (EI - S, 2023). Certain studies show that the use of processing residues and waste water can be beneficial for the soils of sugar beet cultivation. However, if inadequately or poorly applied, this can also lead to negative soil quality impacts (Stevanto et al., 2019; Clemente et al., 2015).

The Global Food Policy Report 2022 suggests reducing food loss and waste along the entire value chain. The amount of agricultural waste and residues from sugar beet is among the lowest compared to other crops with just 0.32 million tonnes of sugar beet residues produced annually, whereas sugar cane residues already amount to 6.8 million tonnes annually (Rosenstock et al., 2019).

Climate impact

There is a lack of literature dealing with greenhouse gas emissions from sugar beet processing in Egypt. A Study by Gonzales et al. (2022) conducted an LCA for a Swedish factory. In this case the sugar beet processing to sugar accounted for 56% of the whole GHG emissions along the whole value chain. These emissions were mainly caused by diesel used for loading and transport, process energy at the factory, and chemicals added as processing aids. However, the factory analyzed in this study was operated using biomass and gas, and only a small proportion operated using a conventional electricity mix. If energy production is essentially based on fossil resources, the greenhouse gas emissions will be even higher. A study by Klenk et al. (2012) analyzed the environmental effects of the sugar value chain for the EU. This study also shows that a large proportion of greenhouse gas emissions can be attributed to further processing due to the high energy requirements. Around half of the emissions occur in the process of steam production, 11% to the drying of the beet pulp and 4% to lime kiln operations.

The experts interviewed confirmed that the processing of beet into sugar is very energy-intensive. The majority of factories in Egypt rely on either oil or gas for energy, which not only has adverse environmental effects but also consumes significant energy resources (EI - S, 2023). Therefore, the adoption of renewable energy sources in this stage to mitigate these issues is therefore recommended. The continued reliance on conventional electricity sources, coupled with a notable absence of investment in alternative clean energy resource, is also a challenge (EI - S, 2023). Governmental financial and technical support plays a key role for energy transition (FGD - C, 2023).

Assessment criteria	Relevance	Explanation	Sources	Notice
Resource use	2	Large amount of water is needed for cleaning (remove the soil from the beet roots) and for further processing (clarification and filtration) and results in high water consumption as the core resource use within the processing phase; Food waste in processing is low compared to other foods	Rosenstock et al., 2019 Cheesman et al., 2004 EI - S, 2023	No explicit data for egypt
Climate impact	3	Considerable amounts of energy are needed for processing; key energy source from fossil energy sources	Gonzales et al., 2022 Klenk et al., 2012 EI - S, 2023	No explicit data for egypt

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
for an explanation see section 3.1.1.

Table 8 Processing Phase HSA summary and Relevance Score

Source: Own illustration

5.1.3. Distribution

Resource use

No literature regarding the resource use of the distribution phase for sugar beets was found. It is assumed that the impact of distribution on resource consumption is low compared to the other stages of the value chain. This was assumed on the basis of the following considerations on the effects of the distribution phase on climate change.

However, the expert interviews and discussions in the focus group showed that storage after harvesting until transport that is carried out in open trucks can cause the sugar beet to dry out. This has an effect on the sugar content of the crops, meaning that the sugar yield can be slightly minimized and more input of the raw product is generally required.

Climate change

No study was found that examined the climate and resource impacts of the distribution of sugar beet in Egypt. However, a similar study from the UK shows that beet transport and sugar delivery account for the smallest share of emissions with only 4% and 1%

respectively. Accordingly, Gonzales et al. (2022) estimated for a Swedish case that only 3% of GHG emissions can be attributed to the transportation of the beets from farm to factory.

This aligns with existing literature that has investigated greenhouse gas emissions within the broader food system or for various other food products: In terms of greenhouse gas emissions, the transport stage itself accounts for just around three percent of greenhouse gas emissions in the food sector (Wiegmann et al., 2005a; Wassmann et al., 2021). According to Poore et al. (2018), transport, retail and packaging have the lowest impact on GHG emissions of different food products. In comparison, emissions related to land use change and agriculture are particularly high (Stefanato et al., 2019). The Global Food Policy Report (2022) states that even effective measures to reduce emissions between farms and retailers can only have a small overall impact. With respect to the entire value chain, initiatives aimed at improving the efficiency of cultivation and production processes can have a significantly greater impact on the emissions balance than measures that focus on reducing the transport of goods (Fritsche et al., 2007).

In the case of Egypt, most of the sugar beet factories are close to the production areas, so transport might not be a huge source of GHG emissions (EI - S, 2023). However, conversations with agricultural representatives revealed that transportation poses a significant challenge, particularly for farmers, since the sugar beet's quality is greatly influenced by the timing of its harvest and its timely delivery to the processing facility. Any delays in transportation can result in a reduction in sugar content and consequently, a decrease in quality, leading to lower profit for the farmer. It was also added that most beets are transported in open trucks, which can also lead to the drying out of the beet and thus to a loss of quality. Thus, to maintain the quality of sugar beet transportation demands precise timing, as delays can cause deterioration that adversely affects both sugar content and overall quality (EI - S, 2023). Thus, transportation of sugar beet poses a significant challenge for farmers. It was recommended to invest in a transportation system that ensures the continuous transport of crops, thereby minimizing the impact on crop quality (EI - S, 2023).

Assessment criteria	Relevance	Explanation	Sources	Notice
Resource use	1	No relevant resource use in comparison to other value chain steps Loss in crop quality/sugar content due to inefficient transportation	EI-S, 2023 Own assumptions	Based on own assumptions following the conclusions on climate change
Climate impact	1	In comparison to other stages of the value chain little impact of distribution on GHG emissions; Cultivation and further processing are located close to each other; cooling not necessary	Tubiello et al., 2022; FAO 2023; Fritsche et al., 2007; Wiegmann et al., 2005a: Wassmann et al., 2021; Gonzales et al., 2022; EI - S, 2023	Based on LCA for a Swedish and UK case and studies investigating the food sector in general

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
for an explanation see section 3.1.1.

Table 9 Distribution Phase HSA summary and Relevance Score

Source: Own illustration

5.2. Results of hot spot assessment

The fact-based research on each of the focus stages of the value chain identifies the highest environmental problems in terms of resource use in the agricultural phase, while considering the Climate impact the agricultural and the Processing phase have major impacts.

Table 10 gives an overview of the identified relevance of each step of the sugar beet value chain.

Lifecycle / Category	Agriculture	Processing	Distribution
Resource use	3	2	1
Climate impact	3	3	1

Relevance: 1 = low relevance, 2= medium relevance, 3= high relevance, - = no data
for an explanation see section 3.1.1.

Table 10 Overview of the relevance of each step in the sugar beet value chain

Source: Own illustration

From the identified relevance of the individual stages in a final step the hot spots are identified. For a better visibility of the hot spots, the relevance of both factors resource use and climate impact are multiplied by each other.

Agriculture: Resource Use 3 * Climate Impact 3 = Total 9

Processing: Resource Use 2 * Climate Impact 3 = Total 6

Distribution: Resource Use 1 * Climate Impact 1 = Total 1

	Agriculture	Processing	Distribution
Environmental Hot Spots	9	6	1

Scale: low relevance = 1 to 9 = highest relevance

Table 11 Hot spots in the sugar beet value chain

Source: Own illustration

5.3. Greening options and focus group evaluation

The hot-spot analysis described above shows that ecological impacts in the area of climate change and resource use occur primarily in the areas of sugar beet cultivation and processing - less in the area of distribution. The greening options now presented therefore relate mainly to these two value chain steps.

Above all, water use, excessive fertilization and energy consumption based on fossil fuels proved to be critical. Nonetheless, it is also important to note that Egypt currently has a very low level of self-sufficiency in food production. Given the competition for limited arable land, it is recommended to allocate the land towards other staple crops such as wheat, rather than sugar beet, which offers inadequate nutritional value. It should be noted, that, the report has not compared sugar beet with other staple crops in terms of the environmental impact of production and the potential area under cultivation so that no statement can be made as to whether a different allocation of the agricultural land is also ecologically favorable or even possible at all depending on the soil conditions.

In the sugar beet focus group discussion, the participants selected eight greening options from those proposed by the project team and those recommended by the participants. The greening options were then evaluated by stakeholders against a set of criteria (see Chapter 3.1.3. Evaluation method of greening options).

The eight discussed greening options are described below. Identified greening options that were not selected for a deeper discussion in the focus group are presented afterwards.

Yield Gap Analysis and applying best farming practices

A yield gap analysis is a valuable method for assessing and addressing the disparities between potential and actual crop yields. By identifying the underlying causes of yield gaps and implementing targeted interventions, it is possible to enhance food security, reduce environmental impacts, and promote sustainable agricultural practices and thereby minimize the exploitable yield gap. This analysis plays a crucial role in optimizing agricultural systems to meet the growing global demand for food while ensuring the long-term viability of farming (FAO, 2016). Yield gaps can result from a variety of factors, including suboptimal agricultural practices, limited access to resources (such as seeds, fertilizers, and irrigation), pest and disease pressures, adverse weather events, and economic constraints. One possible cause of a large yield gap is missing knowledge and the associated sub-optimal use of agricultural practices. Due to a lack of access to education and information especially smallholder farming structures are particularly vulnerable. Often, access to education is difficult and the profession is passed down within the family. Thus, old practices are preserved, but there is little room for new input and new practices especially under rapidly changing conditions due to climate change (FAO, 2016; Lobell et al., 2009). Information and training programmes can help to fill these knowledge gaps and ensure widespread dissemination and application of agricultural practices based on the current and appropriate professional practice.

The focus group discussed how the use of best agricultural practices by training programmes can have a positive impact on resource use and climate change by reducing the use of water, energy, fertilizers, pesticides and other inputs. In addition to these environmental impacts, the FGD considered that there could also be a societal impact by enabling the valorization and conservation of natural resources, increasing farmers' incomes and providing farmers with access to knowledge and information. The measure was rated as very easy to implement and relatively cost-effective. However, a weakness of the greening option is also that it is possible that farmers may not be able to comply with the issued guidelines, when the cultivation practices may result in very high costs for the farmer or if no awareness of the practices can be generated.

Drip irrigation

Conventional agricultural practices and techniques are predominantly employed in Egypt's farming landscape. Particularly along the Nile, where water is freely available in large quantities, farmers continue to use traditional but inefficient irrigation methods in which fields are periodically flooded. Consequently, surface irrigation methods take precedence over drip irrigation. This should be reconsidered, particularly in light of the growing water scarcity issues in the country (EI – C, 2023). Additionally, opting for drip irrigation alleviates plant water stress and enhances overall plant growth and yield potential. Drip irrigation can also play a pivotal role in reducing the risk of pests and diseases. For instance, conventional overhead irrigation methods such as pivots and sprinklers can elevate the risk of leaf diseases due to the leaves getting wet. In contrast, drip irrigation systems maintain the leaves dry, reducing the likelihood of such diseases (EI – C, 2023).

In the discussion about drip irrigation, the focus group clearly mentioned various advantages in terms of resource consumption: Drip irrigation reduces water evaporation compared to various other irrigation techniques and contributes to water conservation and efficiency. Another positive effect of drip irrigation is the ability to control weeds, reducing the need for herbicides and fertilizers. In terms of climate impacts, participants saw the benefits of drip irrigation as a solution to adapt to climate change and improve farmers' resilience to climate risks. However, they also saw disadvantages in terms of climate change, as the irrigation systems require a lot of energy to pump and distribute the water. Especially when pumps are used inefficiently due to lack of knowledge of weather data and information that could be used to plan the use of drip irrigation. The feasibility for the private sector and SMEs is assessed both positively and negatively. Drip irrigation systems are easy to install and reduce the time and efforts used for irrigation in comparison with flooding, sprinkle or other conventional irrigation systems. However, high initial investment costs in equipment and costs and efforts for the maintenance are a disadvantage or rather need government support to be feasible. In addition, the irrigation systems technology used in Egypt is not yet sophisticated enough, and frequently a quality gap in some drip irrigation equipment and materials occurs. As a social impact, the increased demand for the construction and installation of drip irrigation systems also creates new business opportunities and jobs in other sectors (manufacturing). However, there is currently a lack of know-how and expertise in this area, and drip irrigation is not widely available in various regions of Egypt.

Cover crops, crop rotation and intercropping

Crop Rotation refers to the practice of growing different crop species in succession in the same field, planting a different crop each year or season. Crop rotations have been proven to mitigate soil erosion, enhance soil quality and nutrient levels, foster biodiversity, enhance water use efficiency and diminish weed and pest populations. Thus, rotational systems contribute to food security for a growing population in addition to the important ecological aspect (Selim, 2019). A crop rotation system can also be combined with an intercropping system, where multiple crops are simultaneously cultivated in the same field. As a consequence, the benefits of a rotational cropping system are intensified. Additionally, it offers a chance to small scale farmers to combine cash and food crops on one field thus creating an income while practicing subsistence farming (Maitra et al., 2021). Cover Crops are plants grown between main cropping seasons or on fallow fields, later tilled under to add organic matter to the soil. Thereby they protect the soil from environmental impacts (such as wind erosion and aridification), suppress weeds and benefit soil fertility when incorporated into the soil. Alternatively, they can be used as livestock fodder (FAO, 2023; Adetunji et al., 2020; Kocira et al., 2020).

The greening option of intercropping was generally well received by the focus group. In particular, many environmental benefits were highlighted: Intercropping provides carbon sequestration as the plants absorb carbon, it allows for less weed development and therefore less pesticide use, and it contributes to the efficiency of irrigation water use. Some crops, particularly legumes, allow nitrogen to be fixed in the soil, providing natural fertilization. Overall, intercropping leads to a better use of resources such as soil and water and enables regenerative agriculture. As a strength it was also mentioned that it increases farmers revenues and land productivity and results in a higher agricultural production. Weaknesses identified included a lack of awareness of the benefits of intercropping and a lack of feasibility for farmers if they do not have the necessary information and training on the different crops that can be combined.

Use of specific holmer to harvest the leaves for better utilization

Sugar beet leaves cannot be used for sugar production. However, there are numerous possible uses for them: Sugar beet leaves can be utilized as feed for livestock. They contain nutrients and fiber beneficial for animals such as cattle or sheep. Further the leaves can be converted into compost, enriching the soil with organic matter and nutrients. They then can be applied to enhance soil quality in agriculture. Also, sugar beet leaves can be used as biomass for energy production, contributing to the generation of heat or electricity.

The prerequisite, however, is that they are harvested appropriately. An holmer is an agricultural equipment designed for the harvesting of sugar beets. It is a multifunctional machine that extracts the beet roots from the soil, cuts off the leaves and transfers them to a trailer. It is commonly used for large scale farming to achieve a quick and high-quality harvest. The removed leaves can be managed in two ways: they may either be left in the field as a natural mulch, enriching the soil, or they can be chopped into smaller pieces and loaded separately for alternative use. Meanwhile, the uprooted sugar beets are collected and loaded onto large transport vehicles and delivered to the factories. On the other hand, conventional practices when it comes to sugar beet harvesting involve manual labor carried out by small farmers.

The discussion in the focus group on the use of a specific Holmer to harvest the beet leaves emphasized both advantages and disadvantages - however, the weaknesses of the greening option seem to predominate. As strength was mentioned, the better utilization of the beet leaves results in more resource efficiency and sustainability and will increase the farmers revenues. This is contrasted by the fact that the investment necessary to acquire the Holmer is substantial and the greening option is therefore not feasible, especially for small-scale farmers. In addition, there is a general lack of awareness among farmers about the presence and benefits of the specific technology or a general rejection of new or alternative methods. As a weakness in terms of the ecological effects it was mentioned that operating the Holmer requires fuel, which leads to an increase of GHG emissions or compaction of the soil by the Holmer.

Use of by-products

The sugar beet value chain offers numerous by-products that can be utilized in various ways in other sectors of the economy. By utilizing the by-products efficiently, almost 100% of the sugar beet can be processed. The use of by-products has several advantages, including cost minimization, reduced waste and a more efficient production. Thus, the sugar beet harvest, beyond its primary yield, becomes a source of eco-friendly solutions in industries, showcasing the potential for agricultural practices to intersect with and positively impact broader facets of sustainable development.

Part of the **stones and aggregate** attached to the sugar beet harvest can be recovered and sorted after the washing process and utilized in road construction and building projects. Stones recovered from beet washing can substitute quarried gravel.

The utilization of stones and gravel was rated very positively by the focus group. The greening option was rated as feasible for the private sector and SMEs as it will create business opportunities for SMEs. A weakness was mentioned that it will cause transportation costs for transporting the aggregate, which will also cause greenhouse gas emissions. However, this is countered by the positive impact on resources as the use of aggregate will contribute to a better management of waste and a better and more efficient resource use. In addition, it can create job opportunities.

Use of lime as by-products: Precipitated calcium carbonate, commonly known as lime cake, is generated as a co-product during the juice clarification phase in sugar manufacturing processes. It is a sustainable option to amend soil pH value and increase available calcium, significantly reducing the volume of limestone and chalk that would otherwise be quarried and crushed for agriculture and other lime markets. The by-product contains substantial amounts of phosphorus and magnesium, making it deserving of investigation for potential uses (Antunovic et al., 2008; Hassanli et al., 2010).

Also for the use of lime the focus group saw various strengths. Reusing the lime used in sugar production is seen as an ecological advantage as it saves resources if newly produced lime does not have to be used. If the lime is applied to the farmland again and an optimum pH value is achieved, less irrigation is required. The use of lime on agricultural land can increase the farmers' revenues, since the productivity could be possibly higher. The processing and reutilization of lime can also create new business opportunities and markets for SMEs.

However, there was also one statement of a participant that the soil in Egypt is not necessarily suitable for liming. It was therefore recommended that the lime be recovered and not used in agriculture but in other sectors that have a need for lime, such as construction, chemical or paper industry. Also it was mentioned that difficulties in accessing adequate technology to use the lime is lacking.

Further Byproducts were mentioned in the focus group discussion but not discussed in detail in terms of the multi criteria analysis:

After extracting the sugar from sugar beet, the remaining pulp can be pressed to generate high quality **animal feed**. It provides a useful energy food for a wide range of livestock including cattle, sheep, pigs, goats and horses.

Molasses, the residual liquid byproduct obtained after the crystallization of sugar, and vinasse, a liquid residue from the fermentation of molasse in **ethanol production**, both offer valuable opportunities for ethanol production. Molasses, being rich in fermentable sugars, serves as an input for ethanol fermentation. Through the fermentation process, microorganisms convert the sugars in molasses into ethanol and carbon dioxide. This presents a sustainable and economically viable way to utilize the residual molasses, turning it into a valuable resource for biofuel production.

Other by-products of sugar production are sugar beet leaves and vinasse, which can be used as **organic fertilizer.**

Use of green energy

Sugar beet production demands a substantial amount of energy. However, a more environmentally friendly approach involves shifting to the use of renewable energy sources. Egypt's recent decision to reduce electricity subsidies, combined with the increasing competitiveness of photovoltaic energy compared to traditional grid electricity, is contributing to a greener and economically advantageous transformation in the country's electricity supply. In this evolving landscape, photovoltaic technology emerges as a particularly compelling factor in advancing Egypt's green energy initiatives (EI – C, 2023). In the expert interviews it was also mentioned that thermal energy would also be a good alternative to fossil fuels. Furthermore, recent research emphasizes the substantial potential of waste-to-energy techniques within sugar factories and the adoption of renewable bio-electricity, resulting in notable reductions of 4-4.4% in mitigating climate change effects, and 4.18-4.87% in resource preservation (Rajaeifar et al., 2019).

Discussions on the production of green energy in the focus group showed that the experts expect important ecological impacts. The measure can reduce the electricity production gap in Egypt and the production of biogas out of beet by-products will reduce the use of fossil fuel based electricity, and therefore, will reduce the GHGs emissions. Similarly, the effects on resource utilization are also positive as less waste is generated and pollution by the use of fossil fuels is reduced. As a social impact of the measure, the participants in the focus group expected the creation of job opportunities for highly skilled and low skilled employees and more business opportunities for

SMEs. As weakness is considered that the initial costs of the production plants for green energy are very high and there is a knowledge gap on the existence of these measures and opportunities.

Climate insurance

Climate insurance is not a greening option in a narrower sense as it does not enable ecological effects itself but helps especially SMEs to be less vulnerable to climate change. As a strength of the measure, the focus group mentioned that climate insurance enables a more rapid recovery following any climate disaster, and also enhances small holders' resilience towards climate change. In addition to these positive effects on farmers, further strengths for SMEs were mentioned in the focus group. In particular, it was emphasized that the market for climate insurance in Egypt is not yet well established and that there are opportunities to develop a new niche market. This offers opportunities for SMEs to start new businesses such as applications for monitoring climate data or integrating weather information in the planning of agricultural production. Also, climate insurance will encourage the access to financing for small and medium scale farmers as they have easier access to credit due to financial security in the event of crop failures. However, the fact that the market for climate insurance in Egypt is not yet established also poses weaknesses: necessary data and information to assess climate risks, and eventually develop adapted climate insurance schemes for the agricultural sector in Egypt are lacking. It is also mentioned that it is difficult that climate insurance would cover all the agricultural productions and crops. In addition, various social factors were seen as weaknesses. As the market for climate insurance is new in Egypt, the awareness among small scale farmers regarding these insurance schemes is lacking. Further investigation is needed to understand the farmers behavior, handling and practices with farmland under climate insurance. Also, it is unclear how insurances would need to be handled in the special case of sugar beets, as prices have already been negotiated with the refineries through contract farming.

Further greening options that were not discussed within the focus group are Precision agriculture, Mulching and Fertilization with organic material and are presented below.

Precision agriculture

In the realm of precision agriculture, a meticulous approach to fertilizer and irrigation management is gaining prominence. By utilizing advanced sensor technology and analytical tools, farmers can pinpoint precise areas that require irrigation, fertilizer application or pesticide use. This targeted approach ensures that resources are used efficiently, minimizing waste and environmental impact. Another objective of field robotics is to address the issue of soil compaction that often results from the use of heavy agricultural machinery. To mitigate soil compaction, field robotics employs nimble, unmanned vehicles that are specifically designed to minimize their impact on the soil structure. Precision farming methods for sugar beet, encompassing seeding, irrigation, fertilization, harvest, and post-harvest techniques, are under scrutiny for their potential positive impact on cost, time, and quality (Hamada et al., 2011; Mehanna et al., 2017; Moursy et al., 2021; Yassin et al., 2021).

Egyptian agriculture is characterized by many small farmers who often rely on traditional practices. Due to high initial investments, the use of precision agriculture is unrealistic without accompanying measures. Implementing this greening option requires supportive measures, such as government initiatives or cooperations, to facilitate access to modern agricultural technologies and overcome the financial hurdles for small farmers.

Fertilization with organic material

The appropriate application of fertilizers relies on a preliminary analysis of the soil conditions and depends on many factors; therefore, a careful investigation of the site and corresponding conditions is highly recommended. Fertilizers can play a significant role in supporting and enhancing Soil Organic Matter (SOM), which is crucial for soil health and fertility. While fertilizers are typically associated with providing essential nutrients like nitrogen, phosphorus, and potassium to crops, they can indirectly contribute to increasing SOM through specific practices and choices. Using organic material as soil amendments, such as by-products of the sugar beet or cover crop residues, is an excellent way to increase SOM and to reduce the need for applications of other types of fertilizers (Lescure & Affret, 1997). These materials are rich in organic matter and therefore nutrients, and when incorporated into the soil, they not only supply essential nutrients to plants but also contribute to the organic matter content (Magdoff et al., 2005).

Mulching

Mulching is a natural approach in which organic materials, such as plant residues that are readily available on-site - in the case of sugar beet, for instance, leaves - are applied as a layer to the surface of the soil, and is an alternative to conventional weed control methods (which use herbicides or plastic sheeting). Mulching not only suppresses weed growth but also improves the soil by increasing its humus content. In addition, organic mulch acts as a natural moisture barrier, reducing water evaporation from the soil. This helps to maintain consistent soil moisture levels, reducing the frequency of irrigation and helping to reduce water demand. Mulch moderates soil temperatures by insulating the soil. It keeps the soil cooler in hot weather and warmer in cold, creating a more favorable environment for plant root growth. This natural approach is in line with sustainability principles and contributes to the overall resilience of agriculture (El-Metwally et al., 2022).

6. Refrigerator value chain

The stages of the refrigeration value chain include the extraction of raw materials, the manufacturing of components, the production, the retailing and the use of the appliances as well as their disposal or recycling, known as end-of-life. In addition, there are ancillary steps in the value chain that are relevant to more than one stage in the chain, such as transport, packaging, logistics or material input to factories or warehouses.

The refrigeration value chain considered here in the HSA focuses on domestic and commercial refrigerators and on the stages of the value chain that are currently relevant for the local market in Egypt. In terms of resource use and climate impacts, the focus is on the resources and emissions that go directly into or are directly caused by the value chain. Therefore, the focus is on the following stages: parts assembly, retail, use and end-of-life. Figure 13 provides an overview of the refrigerator value chain, highlighting those included in the HSA.

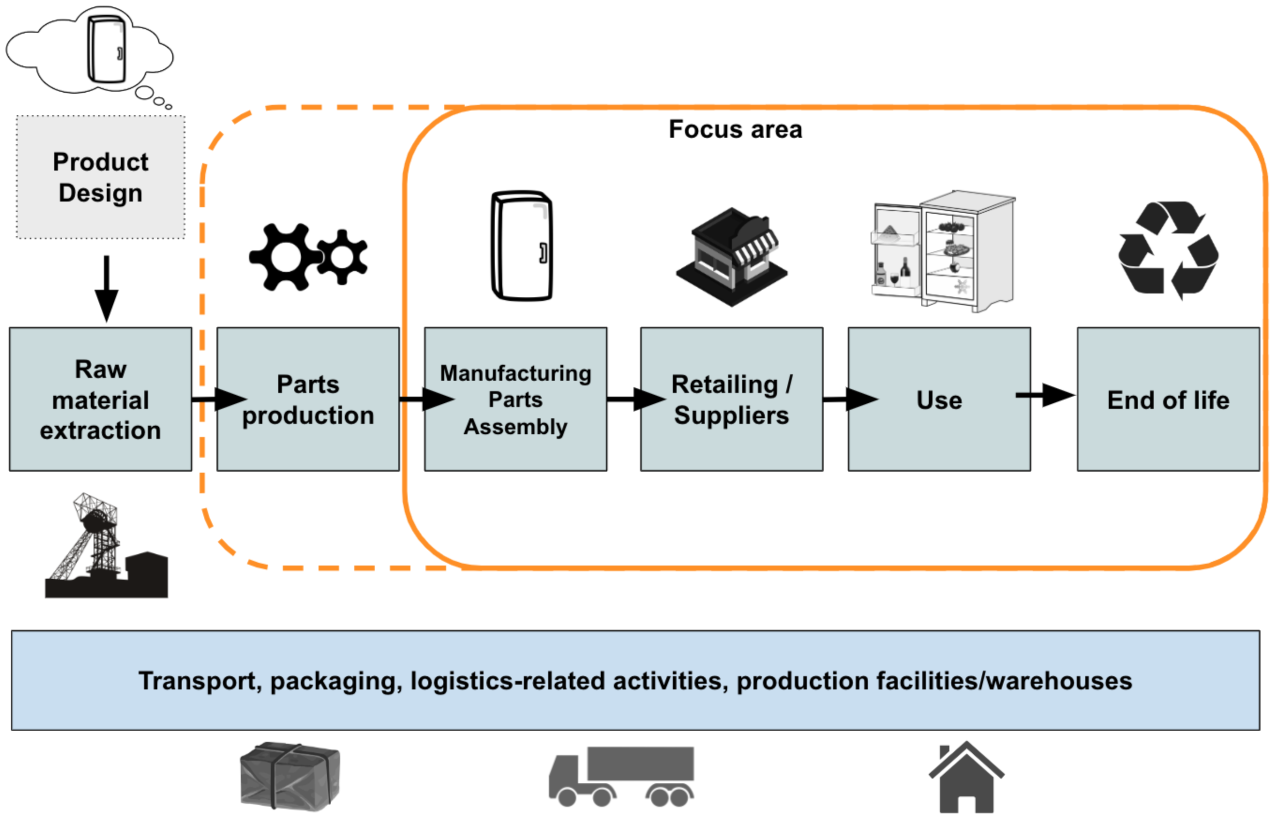

Figure 13 Overview of the stages in the refrigerator supply chain

Source: Own illustration

A stakeholder map was developed to identify relevant stakeholders (see appendix).

6.1. Environmental hot spots

To identify environmental hotspots, key stages of the refrigerator value chain are assessed against the criteria of climate impact (mainly in terms of greenhouse gas emissions) and resource use (including water and material use).

As shown in Figure 13, **the upstream stages of the value chain, product design and raw material extraction, as well as ancillary stages such as transport and packaging, are not considered in detail in the HSA.** This is because these stages involve a large number of individual global supply chains of individual materials and parts, which cannot be comprehensively covered within the scope of this study. The same is currently true for parts manufacturing, with the difference that the Egyptian market has potential for greater SME involvement in this stage of the value chain in the future. Therefore, parts manufacturing is not currently included in the HSA analysis, but is recognized as an important step and therefore briefly described.

6.1.1. Parts/Components manufacturing

An overview of refrigerator components is given in the introduction of chapter 7 and will only be briefly referred to here. The main factors contributing to **GHG emissions in the production of refrigerator parts are the spraying, foaming and vacuum forming of the gasket and the overall energy consumption in parts production** (Xiao et al., 2015). The manufacturing process leads to energy consumption through the use of electricity or heat, or through the activities of subcontractors (Lewandowska et al., 2021). In terms of material consumption, the production of compressors has the greatest impact on the degradation of abiotic elements, mainly due to the use of copper, steel and aluminum (Xiao et al., 2015). In addition, synthetic materials must be considered: polystyrene sheets are used for refrigerator cells, doors and inner door panels of refrigerators (Ferrarini & Benelli, n.d.). In terms of environmental impact, the choice of refrigerant is also of particular importance (EI - R, 2023).

The majority of components for commercial refrigeration in Egypt, especially compressors and controls, and refrigerants are currently imported (Cool Up, 2022). However, there are local manufacturers and suppliers of display cabinets, freezers and refrigerators in Egypt (Cool Up, 2022). Some notable refrigerator manufacturers are Fresh Electrics,Alaraby, Electrolux and Midea (EI - R, 2023). Local companies such as Midea and Electrolux are already using the refrigerant R600a, which has a low global warming potential, in their products (EI - R, 2023).

6.1.2. Manufacturing (Part assembly)

The entire refrigerator manufacturing process involves a number of steps, starting with the design of the appliance, through the upstream value chain steps of raw material extraction and component supply, to component assembly. **The actual manufacture of the refrigerators involves assembling the parts, pressing and metalworking, installing the electrical components and filling the systems with the specific refrigerant and foaming.** Subsequently, assembly, quality control, packaging and labelling take place (Goldstein & Bonaglia, 2005). The manufacturing processes of the refrigerator value chain is shown in Figure 13. *The* manufacturing process of the refrigerator is not very complex in terms of pre-assembly. However, the actual manufacturing step of assembly is the most labor intensive, requiring 100 workers for one line (EI - R, 2023).

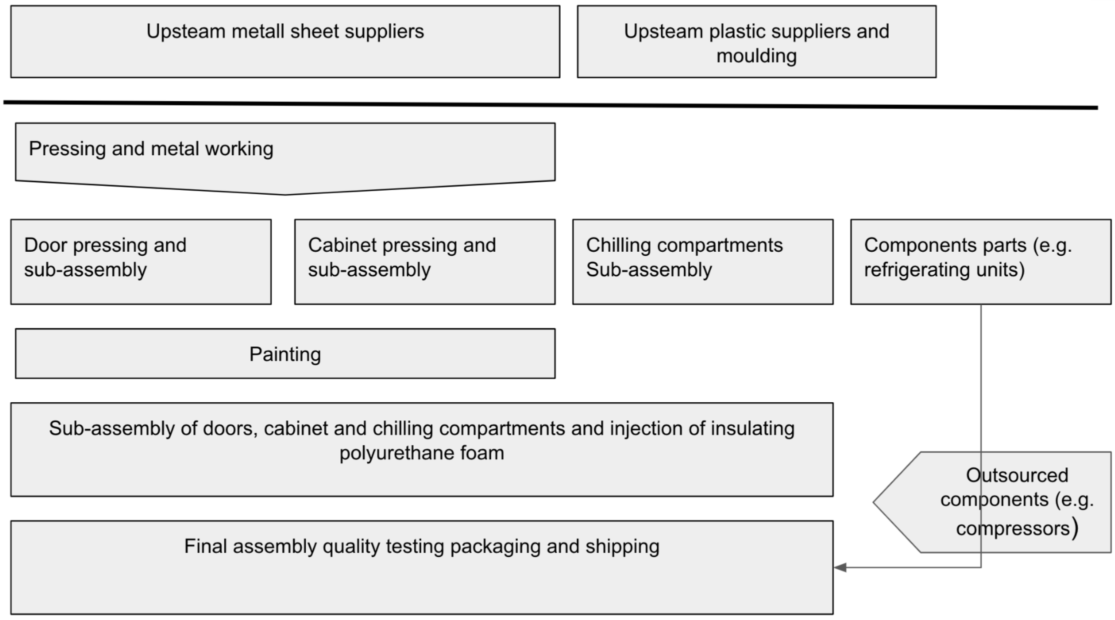

Figure 14 Manufacturing process of refrigerators

Source: Own illustration based on Goldstein & Bonaglia, 2005

Xiao et al. (2015) conduct a life cycle assessment (LCA) for a refrigerator with a typical service life of 10 years in China. The LCA considered factors such as abiotic depletion, GWP, photochemical ozone creation potential and ODP. The study shows that **the environmental impacts of refrigerators are mainly concentrated in the use and production phases** of their life cycle (Xiao et al., 2015). Lewandowska et al. (2021) assume electricity consumption of 10,948 kWh, natural gas and steam in the chemical industry, 10.53 MJ and 7,777 kg for the production of refrigerators in their LCA of refrigerators based on the European energy mix.

In terms of resource use, some manufacturing steps generate large amounts of dissipative losses. For example, the foaming process generates significant waste. In refrigerator manufacturing, the polyurethane material is injected as a liquid between the steel outer shell and the plastic inner liner and expands to fill the space (Imen Polymer Chemical Co., 2022). This results in a combination of materials that is almost impossible to separate for end-of-life recycling (FGD - R, 2023). Another example is the efficiency in the transport of imported refrigerants. Inefficiency often arises because refrigerants are often transported in standardized tanks that cannot be completely emptied during unloading. There is room for improvement to minimize refrigerant losses (EI - R, 2023).

Assessment criteria	Relevance	Explanation	Sources	Notice
Resource use	3	Resource consumption is mainly relevant in the production phase of the upper stages of the value chain: the extraction of raw materials and the production of parts. However, some additional material is consumed during final assembly and manufacturing of the final product. Another important factor is the waste generated during manufacturing due to dissipative losses.	Xiao et al., 2015 Cool Up, 2022 Yu et al., 2012 Goldstein, 2005 EI MENARES 2023	Raw materials and parts production in the upper value chain are not directly included in the assessment.
Climate impact	3	The manufacturing process (assembly of parts) of the refrigerators results in energy consumption through the use of electricity or heat, which is particularly relevant given the fossil fuel-based energy mix in Egypt.	Xiao et al., 2015 2021, Lewandowska EI MENARES, 2023	GHG due to energy consumption. This step does not include the electricity consumption of the upper value chain steps raw material extraction & parts manufacturing.

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
for an explanation see section 3.1.1.

Table 12 Manufacturing Phase HSA and Relevant Scores

Source: Own illustration

6.1.3. Retailing

Retailers in the refrigeration industry include various types of distributors, including own-brand retailers, independent retailers, multi-stores and smaller retailers. These retailers play a crucial role in the distribution of refrigerators to consumers. Retailers (in the EU and the US) are mainly involved in supply chain logistics rather than advanced value-added activities such as design, branding or marketing (Goldstein & Bonaglia, 2005).

The carbon footprint of products at the retail stage includes the retailer's energy management, product packaging, waste management and resources such as lighting, heating, equipment and water (Thompson, 2007). In the case of refrigerators, the retailer does not require any special storage, i.e., the product does not need to be heated or cooled, which generally results in a relatively low climate impact. Relevant factors are the retailer's energy and fuel consumption, either in the store or in transporting the product, as well as packaging and potential waste management. In their LCA of refrigerators based on the European energy mix, Lewandowska et al. (2021) assume a duration of **retailing of 81 days** with an electricity consumption of 31,956 kWh, which is relatively low compared to the energy consumption within the use phase.

Assessment criteria	Relevance	Explanation	Sources	Notice
Resource use	1	At this stage of the value chain, resource consumption is not high as no special equipment is required to store and sell a refrigerator. Relevant resources are considered for packaging and waste generation.	Thompson, 2007 EI MENARES, 2023	-
Climate impact	1	Low relevance of greenhouse gas emissions from electricity consumption.	Lewandowski et al., 2021	-

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
for an explanation see section 3.1.1.

Table 13 Retailing Phase HSA and Relevant Scores

Source: Own illustration

6.1.4. Use

The use phase of refrigerators is the period during which they operate and maintain a desired temperature for the storage of food and beverages. Both Xiao et al. (2015) and Lewandowski et al. (2021) highlight the importance of the use phase in their life cycle assessments (LCA) of household refrigerators. Xiao et al. (2015) shows that the use phase is critical across all factors they considered, and is responsible for the highest environmental impact. Similarly, the findings of Lewandowski et al. (2021) are consistent, emphasizing that the use phase and the associated energy consumption are the most critical components of the LCA. Xiao et al. (2015) and Lewandowska et al. (2021) set the average use phase of household refrigerators at 10 years. However, it can be assumed that the actual lifetime and use phase of domestic refrigerators in Egypt is more likely to be 20 years or more (EI - R, 2023). Users try to keep the refrigerator running as long as it's still functional, even if the performance is poor. Repairing broken parts is more common than replacing the whole appliance (EI - R, 2023; FGD - R, 2023). Paul et al. (2022) show that technical ageing mechanisms can additionally increase the electrical energy consumption of a refrigerator by up to 36% over a product lifetime of 18 years. The impact of climate change on domestic and commercial refrigeration is another factor to consider. In their study, Borikar et al. (2021) examine the effects of ambient temperature, fresh food compartment temperature and heat load on the energy consumption and coefficient of performance (COP) of refrigerators. The results show that both heat load and ambient temperature have a significant impact on the energy consumption of refrigerators.

For the use phase, it is also important to consider which appliances are used and how energy efficient they are. Abed et al. (2015) conducted a study in Egypt to analyze consumer preferences by testing energy efficiency labels and other factors influencing the promotion of energy efficient refrigerators. Energy efficiency labels are informative indicators placed on products that provide information on energy performance and efficiency, helping consumers to make informed choices when comparing similar products. Several models from brands such as Hitachi, Samsung, White Whale, Toshiba and LG were included in the study. The study identified four criteria: brand, price, model and energy consumption. It shows that **brand and price are the most important decision criteria for users in Egypt, followed by model and energy efficiency.** However, the importance of these factors varies according to the consumer's income level. High-income consumers prioritize brand, followed by energy consumption. In contrast, low-income consumers prioritize price, followed by the brand and model of the refrigerator. Furthermore, Abed et al. (2015) highlight that the majority of consumers have neither seen nor considered energy efficiency labels in their purchasing decisions. The Chilling prospects report is consistent with the findings of Abed et al. (2015). It shows that people on low incomes tend to buy the cheapest fridges, while people on middle incomes can afford and choose more energy-efficient models (Sustainable Energy for All, 2021).

Therefore, due to the longer lifetime and potentially higher ambient temperatures, it is assumed that the energy consumption and reduced energy efficiency may have an even greater environmental impact for refrigerators in Egypt than assumed in the studies by Xiao et al. (2015) and Lewandowska et al. (2021).

The total air-conditioning and refrigeration (RAC) sector in Egypt is responsible for almost 20 MT of CO_2 equivalent (GCI, n.d.). **Domestic refrigeration had total emissions of about 2.6 MT of CO_2 equivalent in 2016, while commercial refrigeration was responsible for 3.2 MT of CO_2 equivalent in the same year** (GCI, n.d.). For domestic refrigeration, refrigerant leakage has almost no impact, while for commercial refrigeration leakage is still high, accounting for about 43% of total commercial refrigeration emissions (GCI, n.d.). If current trends continue (in a business-as-usual scenario), the GCI projects that emissions from the commercial refrigeration sector in Egypt will continue to grow, reaching 6 million tonnes of CO_2 equivalent by 2050. However, in a mitigation scenario, this trend can be reversed, leading to a reduction in emissions to around 2 million tonnes of CO_2 equivalent by 2050, mainly by reducing the use of harmful refrigerants (GCI, n.d.). For the domestic refrigeration sector, the GCI projects an increase in emissions: It is estimated that emissions will reach around 5 Mt CO_2e by 2050 in a business-as-usual scenario and around 4 Mt CO_2e by 2050 in a mitigation scenario (GCI, n.d.).

Assessment criteria	Relevance	Explanation	Sources	Notice
Resource use	3	Resources are used to replace and repair broken parts of refrigerators to extend the life of the appliance.	Expert Guess WI EI MENARES, 2023	-
Climate impact	3	The use phase and use related energy consumption have the highest climate impact from energy consumption, which is more relevant given the fossil fuel based energy mix in Egypt. Refrigerant leakage (mainly in commercial refrigeration) can also cause direct emissions. In addition, most refrigeration appliances in Egypt have a long lifetime and energy efficiency is not the most important factor when choosing a new appliance. Emissions are expected to continue to increase, and energy consumption may increase further as ambient temperatures rise.	Borika et al., 2021 Country data - Green Cooling Initiative, 2023 Xiao, 2015 Lewandowski, 2021 Abed, 2015 EI MENARES, 2023	-

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
For an explanation see section 3.1.1.

Table 14 Use Phase HSA and Relevant Scores

Source: Own illustration

6.1.5. End of life

End of life (EOL) is the final stage in the life cycle of a product. For refrigerators, the EOL phase is the period from when the refrigerators are no longer used, maintained and therefore disposed of or recycled.

In Egypt, there is no standardized process for the end-of-life management of refrigerators. According to one expert in a focus group discussion, Egyptian culture emphasizes charity and the concept of not wasting resources. As a result, people tend to donate damaged goods to people in need or, if an appliance is broken, to sell or donate the parts rather than throw them away. End-of-life management is therefore characterized by an informal second-hand market. Functional components are often removed and sold separately, even if the refrigerator as such is no longer functional. Components that are considered unusable or unsuitable may also occasionally be recycled, especially if they have a material value. Otherwise, they are usually disposed of as general waste. However, the disposal of the refrigerant in these appliances poses a significant problem. Insufficient recycling of refrigerants can lead to environmental and health risks. In some cases, companies encourage customers to bring in their old equipment by offering discounts on new purchases, but in most cases these companies do not reuse the spare parts from the old equipment. Instead, this practice is primarily a marketing strategy (EI - R, 2023). In the refrigeration sector, additional emissions can occur at the end of the life cycle due to the release of refrigerants without proper recovery and recycling facilities; the most direct emissions occur when the refrigerant is changed when a unit is dismantled (Technology - Green Cooling Initiative).

Various analyses focus on possible ways to recycle or dispose of refrigerators. Xiao et al. (2015) divide the refrigerator disposal process into the following stages: artificial disassembly, crushing, magnetic separation, winnowing and eddy current separator. At this stage, steel recycling reduces the environmental impact of the appliance. Recycling the high impact polystyrene (HIPS) reduces the global warming potential. According to Xiao et al. (2015), the disposal stage of household refrigerators is only a small factor contributing to the GWP. Recycling of steel and copper are relevant factors for the ADP elements. The Öko-Institut (2007) carried out a study on different possible disposal routes for CFC- and hydrocarbon-containing household refrigeration appliances. These include those that could result from possible changes to the European WEEE Directive. The recycling process first involves vacuum extraction/removal of CFCs or HCs and refrigerant fluid from the refrigerant circuit and removal of glass, condensers, compressors, shelves and loose plastic parts. The appliance is then shredded to separate PU foam, polystyrene, iron and other components. The shredding process can be carried out either separately for the refrigerator or together with other electrical appliances and shows that the plastics, metals, glass and oils from the refrigerators can potentially be recycled. This process generates additional emissions from the sorting and shredding facility through the use of electricity and fuel to transport the appliances to the recycling or shredding facility (Öko Institut, 2007).

Assessment criteria	Relevance	Explanation	Sources	Notice
Resource use	3	There is no official recycling system in place in Egypt. However, equipment contains key materials such as steel, aluminum, plastics and copper that have significant recycling potential. An informal market for recycling exists, but there is a significant risk of valuable resources being wasted in the absence of a well-established recycling framework.	Xiao et al., 2015 Lewandowski et al., 2021 Dehoust et al., 2007 EI MENARES, 2023	-
Climate impact	2	The recycling and disposal of equipment uses electricity, which generates emissions. In addition, emissions can occur if refrigerant is not properly recycled and leaks into the environment.	Dehoust et al., 2007 Green Cooling Initiative EI MENARES, 2023	-

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
For an explanation see section 3.1.1.

Table 15 End of life Phase HSA and Relevant Scores

Source: Own illustration

6.2. Results of hot spot assessment

The research on each of the focus stages of the value chain identified the highest environmental problems in terms of **resource use in the manufacturing, use and end-of-life** phases. In terms of **climate impact, the manufacturing and use phases** have the greatest impact. Table 16 gives an overview of the identified relevance of each step of the refrigerator value chain.

Lifecycle Category	Manufacturing	Retailing	Use	End of Life
Resource use	3	1	3	3
Climate impact	3	1	3	2

Relevance: 1 = low relevance, 2 = medium relevance, 3 = high relevance, - = no data
For an explanation see section 3.1.1.

Table 16 Overview of the relevance of each step in the refrigerator value chain

Source: Own illustration

Identification of Hot Spots

From the identified relevance of the individual stages in a final step the hot spots are identified. For a better visibility of the hot spots, the relevance of both factors resource use and climate impact are multiplied by each other.

Manufacturing: Resource Use 3 * Climate Impact 3 = Total 9

Retailing: Resource Use 1 * Climate Impact 1 = Total 1

Use: Resource Use 3 * Climate Impact 3 = Total 9

End of Life: Resource Use 3 * Climate Impact 2 = Total 6

For the combination of environmental impact factors, the phases are weighted according to both criteria. The combination of resource use and climate impact shows that the manufacturing and use phase has the highest relevance, followed by the end-of-life phase with medium relevance and finally the retail phase with the lowest relevance.

	Manufacturing	Retailing	Use	End of Life
Environmental Hot Spots	9	1	9	6

Scale: low relevance = 1 to 9 = highest relevance

Table 17 Hot Spots in the Cooling Value Chain

Source: Own illustration

6.3. Greening options and focus group evaluation

Along the mapped value chains, resource efficiency and cleaner production opportunities (options) are identified to reduce resource use and carbon emissions, hereafter referred to as *greening options*. These options may include changes in operations, use of alternative inputs, modification of equipment or replacement of technologies with new, more efficient processes or technologies.

They are intended to reduce the environmental impact of the identified environmental hot spots. However, **the following greening options have also been identified for the stages of product design, parts manufacturing, end-of-life and some secondary processes**. Figure 18 provides an overview of the stages for which greening options were identified.

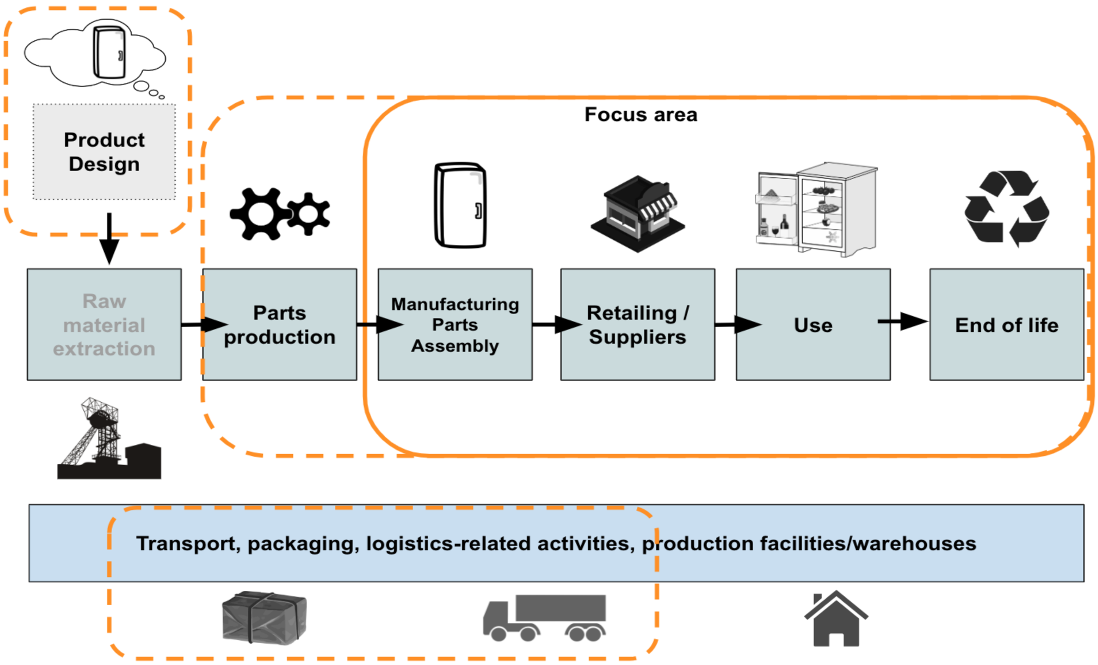

Table 18 Overview of the stages for the identification of greening options

Source: Own illustration

In addition to the research-based greening options, new greening options were added by the stakeholders participating in the expert interviews and focus group (FGD - R, 2023). The options suggested by the focus group are often more specifically adapted to the local context in Egypt or have a high relevance for Egyptian SMEs. Out of all the greening options, the focus group participants selected eight greening options for the evaluation of strengths and weaknesses (see methodology chapter 3.1.3). These eight evaluations are included description of the greening option.

Circular and energy efficient design

One key greening option is the design of refrigerators. One option is to focus on a **modular design, where individual components can be easily separated and partially repaired, reused, refurbished or recycled.** The technical components are bundled in a technical section. Due to the compact design, it will be easier to extract the refrigerant during the treatment process. The removal of electronic components is also easier, as the parts are not encapsulated in foam and are mounted visibly.

In this matter electrical components could be separated from the cabinet (Wuppertal Institut / Tochtrop, 2023). This is intended to **reduce the material flow generated by the cooling service and increase the quality of the recovered materials**. The product life span of the fridge-freezer combination is likely to be extended thanks to the modular design, as it will be easier to repair individual parts. Defective parts can simply be replaced or repaired. Especially, technical parts are well accessible, meaning that repairing the fridge-freezer does not require a great deal of disassembly. The closed cooling circuit means that in-depth repairs can be carried out more efficiently in well-equipped workshops than by technicians on site.

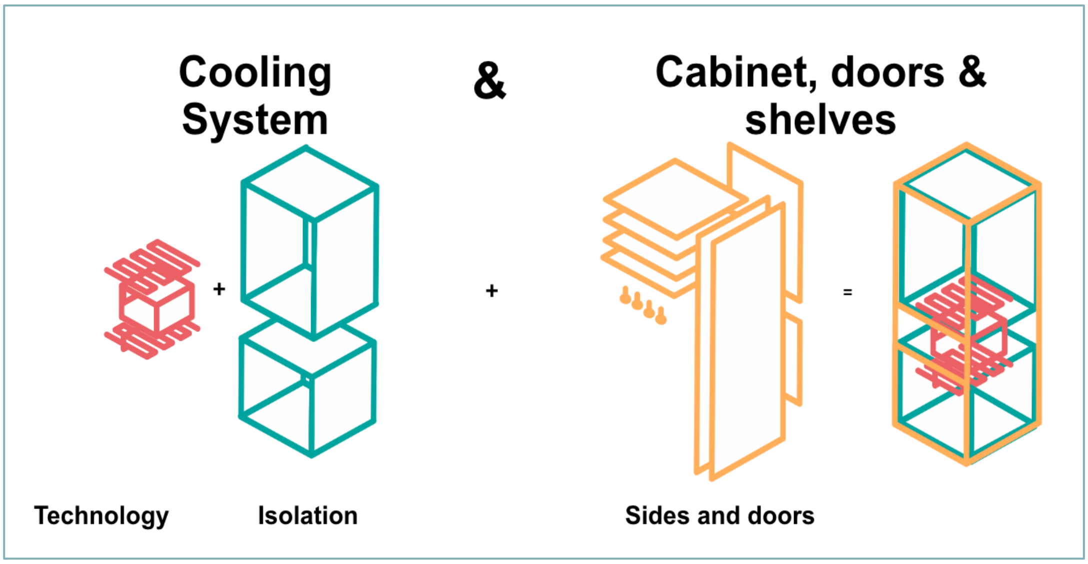

Figure 15 Characteristics of an innovative modular design concept

Sources: Tochtrop, 2023; Tochtrop et al., 2022

Figure 16 Modular design concept

Sources: Tochtrop, 2023; Tochtrop et al., 2022

The focus groups supported the idea of reducing the mixing of materials that cannot be easily separated for recycling, such as plastics and metals. In addition, the focus group highlighted the potential for designing more energy-efficient refrigerators: either the appliance itself or individual parts such as compressors. An additional greening option suggested by the focus group is the use of inverter technology in refrigerators, which allows the compressor to adjust its efficiency according to the outside temperature and the load on the refrigerator (Taneja, 2022). The focus group discussion on the integration of inverters in refrigerators identified several strengths. For the private sector and SMEs, inverters are seen as a practical and readily available technology. In terms of climate impact, it has the advantage of saving energy and reducing greenhouse gas emissions. In terms of resource impact, the technology is consistent with the use of renewable energy in the home. Socially, it promises capital savings for households and users. However, a major concern is the higher initial cost for consumers (FG - R, 2023).

Eco-friendly materials

One greening option to reduce the climate impact of refrigerators is the use of natural refrigerants, which have a high potential to reduce greenhouse gas emissions (Stallmann, 2022). Natural refrigerants include CO_2, NH_3, and hydrocarbons such as R290, R600, and R600a, which have lower global warming potential (GWP) and ozone depletion potential (ODP) (Emani & Mandal, 2018). In Egypt, the potential for the use of natural refrigerants such as R600 is seen (EI - R, 2023). Focus group participants also highlighted the overall importance of using low ODP and GWP refrigerants. Here, participants stressed the importance of additionally developing better recycling strategies for the refrigerant (FGD - R, 2023).

Another greening option to reduce resource impacts is to reduce the overall use of plastics and foams in appliances. Yu et al. (2011) conducted an analysis of Chinese SMEs involved in refrigerator manufacturing to identify areas for potential environmental improvement. They suggest that reducing the use of commonly used low-cost thermoplastic polymers is one of the most cost-effective measures for environmental improvement. The Expert interviews here suggested the use of bioplastic components to subsidize other polymer materials as a material alternative (EI - R, 2023). Regarding the use of alternative materials, the focus group explored the use of bioplastics as a greening option, which was seen as a potentially environmentally friendly material. However, it was noted that bioplastics are not currently widely available. For the private sector and SMEs in Egypt, the integration of bioplastics could strengthen the green economy. However, a notable weakness is seen in the low level of consumer awareness of these environmentally friendly materials. In terms of social impact, the adoption of bioplastics and similar environmentally friendly materials could lead to the creation of green jobs, contributing positively to the workforce and the environment. The Wuppertal Institute project members emphasized to incorporate target conflicts, such as land use and the use of pesticides for e.g. cornstarch as a basic resource for producing bioplastic. In addition, a high energy demand in the production phase of bioplastic should be considered.

Two additional options were added to this topic in the focus group discussion. It was suggested to reduce the negative impact of insulating foam by replacing it with either a water-based foam or insulating panels. Currently, plastic polyurethane foams are widely used because of their low thermal conductivity and light weight (Imen Polymer Chemical Co., 2022).

The water-based foam would have the same properties as the plastic-based foam, but would be biodegradable and dissolvable to allow recycling of the other parts. This option would reduce the environmental impact of recycling and manufacturing. By using a water-based foam, it would be possible to separate individual parts for repair and reuse and reduce the amount of plastic used. However, this idea requires development and innovation to become a viable solution. The use of water-based foam is seen as a cost-effective and safe handling option that is feasible for private companies and SMEs. However, it may require major changes to the design of refrigerators, which could limit its applicability. In terms of climate impact, this approach is seen as beneficial by the focus group as it avoids the use of potentially harmful materials, reduces environmental and climate risks and increases recycling capacity. From a social perspective, water-based foam could reduce a hazardous risk to users, workers and employees and provide a safer alternative.

The other idea was to use insulating panels instead of foam. This concept is already used in freezers and medical refrigerators. The separate insulation panels would create individual parts that could be replaced for easier repair and recycling. This technology is not currently used in domestic refrigerators, but the focus groups see potential for further development (FGD - R, 2023). This idea could be combined with the module design aspects presented above. The focus group discussions on the idea of using insulation panels instead of foam showed that the strengths were seen in increased energy efficiency, reduced need for plastic-based foams and therefore reduced resource impact. For private companies and SMEs, this initiative offers the strength of increased energy efficiency in appliances. However, challenges are seen in wider applicability, as the technology is more suitable for freezers used in medical settings than for average household refrigerators. In terms of climate impact, replacing foam with insulation panels could lead to reduced energy consumption and therefore reduced greenhouse gas emissions.

Changes in consumer behavior

The greening potential of refrigerators is also seen in changes in consumer behavior. As the IEA shows, **people's daily behavior and choices at home are important drivers of household energy use** (Cornago, 2021). Changes in daily habits can help to reduce household energy consumption and related carbon emissions, as well as reducing pressure on the electricity grid. Possible behavioral changes in refrigerator use would include proper use of the appliance, e.g. closing the doors, storing food properly in the fridge or keeping the fridge out of heat, such as direct sunlight. One suggestion from the focus group was to produce a better and simpler user manual for consumers to reduce the barrier to fridge maintenance (FGD - R, 2023). Another recent suggestion comes from Baba et al. (2023), who propose an augmented reality (AR) system that places an agent over the household appliance in question that changes its behavior depending on the internal state of the appliance.

Another option is the decision to replace an old and inefficient fridge with a new and more energy efficient model. However, **there are currently barriers identified by the focus groups.** The first is the low price of energy in Egypt, which prevents consumers from realizing the cost savings of a more efficient appliance. The second is that, as shown by Abed et al. (2015), consumers choose a refrigerator mainly based on its purchase cost and brand, and not on its energy efficiency. Another factor is consumers' low awareness and knowledge of energy efficiency labels on refrigerators. It was suggested that brands could raise awareness by making labels more prominent, and by including the actual amount of cost savings for more efficient appliances.

An alternative greening option to reduce the resource consumption of a refrigerator could be to offer a rental model. This is already a common practice for commercial refrigerators in Egypt, which are often supplied by the individual brands of the products they display, such as ice cream or drinks. An Egyptian example of the rental option for commercial refrigerators is All-Biz Ltd: Lease and Rental of Refrigerators Egypt (All-Biz Ltd, 2023). However, the focus group highlighted that this option is unlikely to be adopted at household level in Egypt, as the concept of rental does not fit with the current cultural practice. It was considered a more realistic approach to encourage the consumer to return the appliance to the supplier at the end of its life. It was suggested to educate the user through the warranty and user manual and to create an exchange policy to motivate the consumer to return the appliance. It was mentioned that the incentive could be increased if the company offered a voucher or cash for the returned appliances. Another idea was to use a QR code and an app where people could register their fridges so that manufacturers could track them and consumers could be advised on how and where to return or repair them (FGD - R, 2023).

After-sales services

In Egypt, refrigerators are more likely to be repaired when needed rather than replaced or rented. This has the potential to increase the lifetime of refrigerators. In addition, the resource impact of refrigerators can be reduced and the energy efficiency of refrigerators in operation can be improved. **The proposed greening option is therefore the introduction of a formalized after-sales maintenance service**. In this service, local refrigerator manufacturers could potentially work with local SMEs to provide a high level of maintenance and ensure the quality of replaced parts. There is currently an informal market for repair and service in Egypt (EI - R, 2023). This service is particularly interesting for commercial refrigeration systems, where after-sales service is more likely to be available. This could be combined with a digital product passport, where all relevant information about the refrigerator is transparent, including repair and maintenance instructions, to promote efficient and long use of the refrigerator.

In the focus group discussion, participants suggested the establishment of third-party companies to formally organize the repair and recycling of refrigerators and other household appliances, with a focus on SMEs. It was emphasized that this currently requires a legal framework that would create the basis for the establishment of these third party companies. Incentives would also need to be created to help SMEs to invest. In addition, specific expertise in the recycling of certain refrigerator components should be created for SMEs, best coordinated with local manufacturers to enable direct cooperation. The benefits are seen in creating links between SMEs, producers, consumers and regulators. Existing informal practices, such as the refurbishment of old refrigerators or the sale of spare parts, suggest the potential for success. Challenges are seen in the initial investment and in managing the full recycling of appliance parts. For companies and SMEs, the need for training in the handling of hazardous substances in refrigerators is mentioned. The climate impact is seen as favorable as it reduces the consumption of energy, water and resources needed to produce new parts. In terms of resource impact, this approach is seen as potentially effective in reducing the use of raw materials and energy, with the social benefit of create (FGD - R, 2023).

To formalize the existing informal market of workshops, the focus group suggested a GOEIC (General Authority for Exports and Imports Control) certification for workshops and manufacturers to develop compliant services. Such compliance could ensure controlled and monitored waste management and the use of certified materials and spare parts in the maintenance of old refrigeration appliances for longer life and efficient operation. For the private sector and SMEs, certification is cost-effective and useful for quality control. A limitation of this option is that it is more suitable for exporters than for the local market. In terms of climate impact, the strength of certification could be in extending the life of products, thereby reducing emissions. In terms of social impact, it promotes resource efficiency through longer product use, but faces the challenge of limited awareness. Finally, certification is seen as having the potential to promote job creation (FGD - R, 2023).

Using Solar Energy

One greening option to reduce emissions from energy consumption at all stages of the value chain is to switch to renewable solar energy. At the household level, for commercial refrigeration users such as hotels, restaurants, retail shops or manufacturing plants, this could be achieved through photovoltaic panels. Mazuk et al. (2022) discuss the potential of integrating greening and solar energy systems into the building sector in Egypt to improve building performance, reduce resource consumption and mitigate environmental impacts in urban areas. This potential could also be extended to buildings for refrigeration storage and SMEs. Overall, the focus group discussions showed a high potential for scaling up solar energy along the value chain (FGD - R, 2023).

Another option suggested in the focus group discussions was district cooling combined with solar energy. In Egypt, this would be of particular interest for compound buildings. The suggestion was to create cold rooms, similar to those in hotel buildings, where food is stored collectively, with the addition of using solar energy from PV panels on the roof as the energy source. An absorption system would be used for cooling and to provide cold water for households. However, it was pointed out that cooling temperatures would be limited to zero degrees and that this option would not allow freezing of goods, but could be combined with other cooling options such as air conditioning. This option could also take advantage of other benefits such as modular design of rooms or collective delivery of food to further reduce emissions and resources. As the business model for district heating already exists in Egypt, it could be used and adapted for district cooling. It was suggested that district cooling systems could be installed by designated energy service companies, which could potentially be SMEs. The focus group discussions on solar district cooling identified many strengths of this option. For the private sector and SMEs, the strengths of district cooling are seen in its existing presence in the energy supply sector and its potential for adaptation to residential buildings (currently present e.g. in supermarkets). The concept, similar to district heating in Europe and North America, would be feasible and transferable. In terms of climate impact, district cooling is seen as having the potential to use absorption processes to reduce climate impact compared to traditional refrigerants. Finally, the focus group believes that the promotion of district cooling could stimulate the creation of new companies and SMEs focused on managing cooling supplies, generating revenues and creating employment opportunities.

Local green manufacturing and retailing

One greening option for the manufacturing process with high potential for SMEs suggested by the experts interviewed during the data collection is the perceived **potential to shift to local parts production. The potential lies in reducing dependence on imports, boosting local production and the economy.** Potential for parts production is seen in parts such as doors, glass panels, shelves, magnets and seals. These components can be produced in small local workshops without the need for complex machinery. There is currently a gap for SMEs to participate in the refrigerator supply chain. The challenge for SMEs is to meet the quality standards required by manufacturers, who use global key performance indicators (KPIs) to maintain quality and performance standards. To change this, it would be necessary to increase collaboration between large manufacturers and SMEs to provide R&D, technology and knowledge transfer, training and capacity building programmes. This could help realize the potential for local manufacturing (EI - R, 2023).

This potential for local production could be enhanced through green retailing: Thompson (2007) provides an overview of the various ways in which retailers can become 'green'. These include suggestions such as using LEDs and low energy bulbs for lighting, using green energy, green home delivery or a green travel plan (Thompson, 2007). Another way to reduce GHG emissions at the local retail level is to set up collective transport of white goods in certain areas to reduce emissions from fossil fuels. This can be applied either to retailers or to end-users so that deliveries are organized collectively across Egypt (EI - R, 2023).

A final third step in creating local green manufacturing is the improvement of ecologically optimized packaging. This is a potentially interesting greening option for SMEs in Egypt, as the packaging material could also be produced locally by SMEs and reduce the impact on resources (EI - R, 2023). Yu et al. (2011) suggest that the adoption of ecologically optimized packaging is one of the most cost-effective measures for environmental improvement, besides reducing the use of low-cost thermoplastic polymers. As SMEs can potentially be increased as suppliers of packaging materials to the refrigerator sector and other sectors in Egypt, this could reduce resource consumption in several sectors. In addition, the greening options introduced for manufacturing processes and environmentally friendly materials can be applied at this stage (EI - R, 2023).

7. Recommendations

To support the transition to a green economy in Egypt, this chapter briefly summarizes key recommendations based on the analysis carried out in this study. The focus is on the role of SMEs in greening their operations and participating in the transition to a green economy.

A short-term recommendation is to initiate strategic value chain collaborations with Egyptian and global value chain stakeholders to prepare the implementation of the evaluated greening options in each value chain. The results of this study indicate relevant hot spots, stakeholders as well as strengths and weaknesses of several greening opportunities as a profound basis. The identified greening options, just as developing circular design concepts for refrigerators and textiles or using by-products of farming process, require to overcome organizational borders in innovative value chain cooperation. Moreover, it is recommended to **investigate further value chains in Egypt with strong SME involvement and high GHG emissions/resource consumption**. In addition, a **sector-specific analysis** should be carried out in order to identify optimal political and economic measures. Especially the **transitioning to renewable energy** is a cross-sectoral challenge that has been prioritized by involved experts in this study.

A medium-term recommendation is to strengthen **capacity building with regard to overcoming the identified ecological hot spots** of the three value chains. A key recommendation in this regard is to set up an agency with a public private partnership form and a mandate to support the three value chains in decarbonization and dematerialization through:

- Capacity building of already active artisans from the informal sector in setting up formal businesses (e. g. recycling of refrigerators).
- Information and raising awareness at the level of the director actors in the three value chains such as: manufacturers of refrigerators, informal artisans, federations, ministerial departments.
- Build capacity of these actors in order to facilitate sustainable product and process innovations.
- Enhance and create dynamic cooperation among all the actors involved in each value chain with the aim to create tangible cooperation mechanisms and overcome organizational barriers.
- Encourage research and industry collaboration on the greening options testing, development and implementation in line with the LivingLab approach (Liedtke et al 2015).
- Promote the cooperation with financial sector actors in order to create adequate financial mechanisms for the implementation of greening options that requires important up-front investments. This includes innovative promotional programs, that encourage SME in investing in greening measures through risk assumption and interest subsidy.
- GoE subsidises greening measures because they will contribute also to address strategic goals for the country such as saving water, saving energy,

consolidating SMEs competitiveness at the international level and capacities to export, and creating employment.

In line with the objectives of Egypt's sustainable development strategy, a **long term recommendation** is to **strengthen a global cooperative regional economy approach** (Liedtke et al., 2020). This approach encompasses three key development goals:

1. **Strengthen Egypt's transformative innovation cooperation networks:** globalizing competencies and cooperation with regard to sustainable technologies and business models (e. g. circular design and sustainable business models in cooling sector, sustainable agricultural practice) and regionalizing material flows in line with international standards (e. g. sustainable cotton produced in Egypt that incorporates EU standards, such as EU Organic Program). This leads to strong cooperation between regions and municipalities for value chain resilience and reduces inequality along the regions among the value chains.
2. **Mandatory alignment of sustainable supply chains related to Egypt's economy** (acting in shared responsibility), with applying international standards and to guarantee human rights and environmental due diligence (including incentive, control, monitoring and sanction mechanisms). In this manner, Egypt's SME will be able to differentiate themselves and gain competitive advantages and access to global markets.
3. **Promoting sustainable public procurement in Egypt** with concerted, globally networked with federal, state and municipal authorities. This encompasses development of appropriate legislation to ensure procurement of sustainable and innovative products and services. This could promote SME market stimulation towards innovative products and service development.

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Appendix

Stakeholder mapping

A stakeholder map was developed to identify relevant stakeholders. The following figures summarizes the results in terms of stakeholders at each stage of the value chain for Egypt. In addition, key stakeholders were identified (see section 3.1.2 for more information on the stakeholder mapping methodology). The figures does not claim to be a complete overview of stakeholders.

Cotton stakeholder mapping

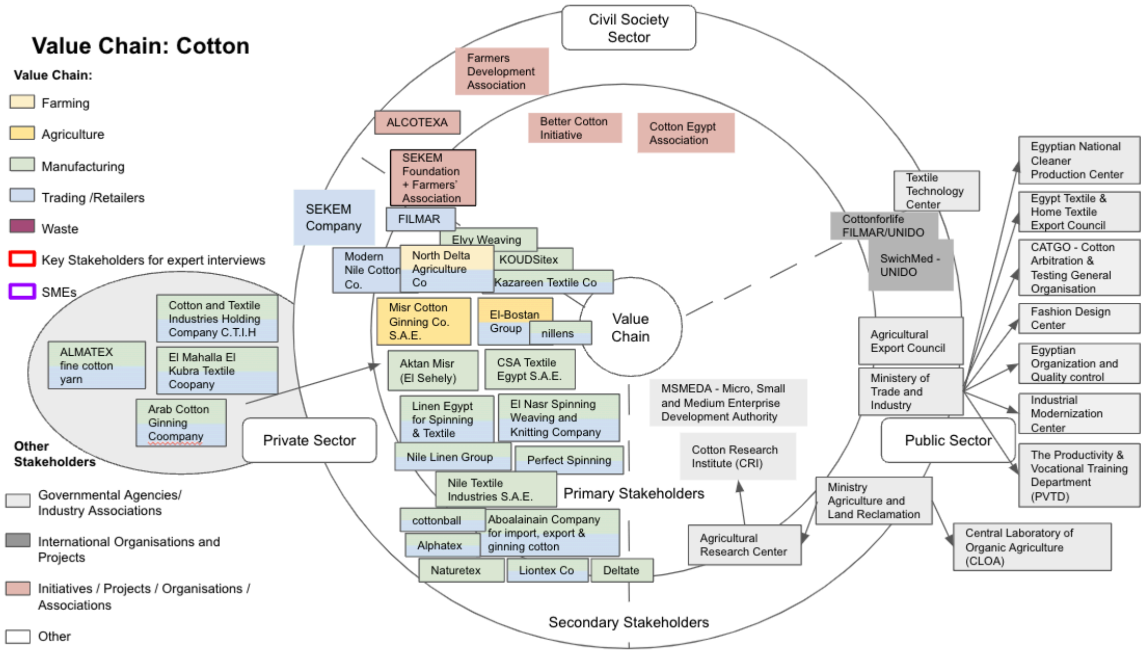

Figure 17 Cotton stakeholder mapping

Sugar beet stakeholder mapping

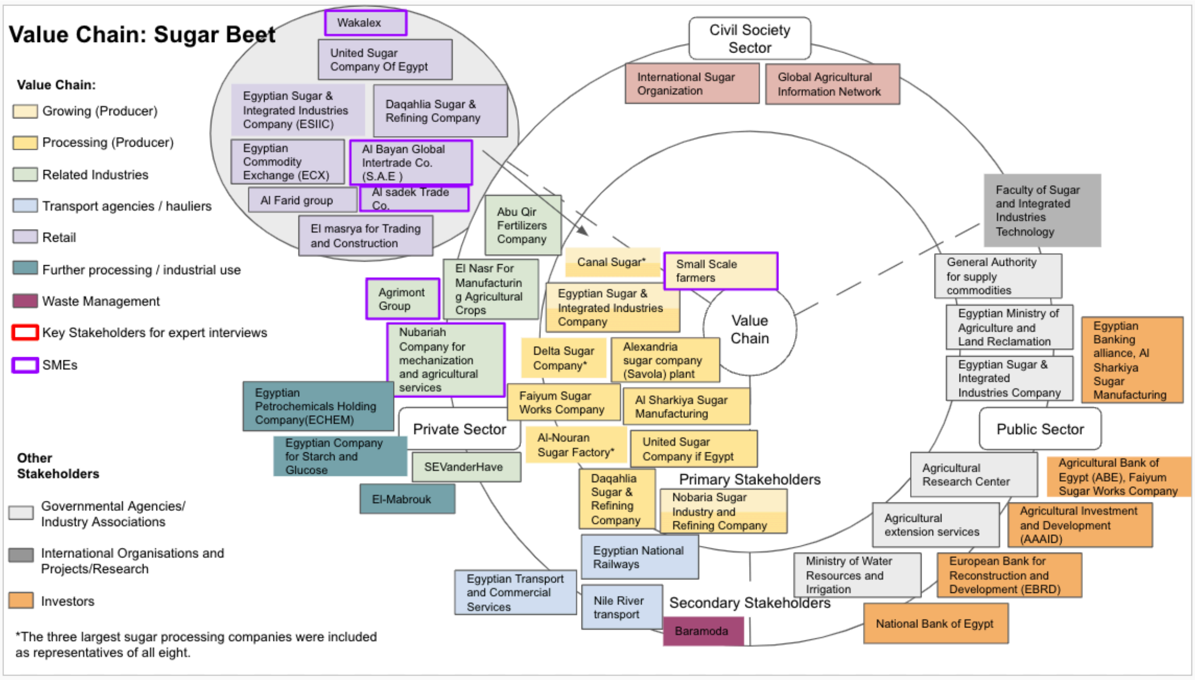

Figure 18 Sugar beet stakeholder mapping

Refrigerator stakeholder mapping

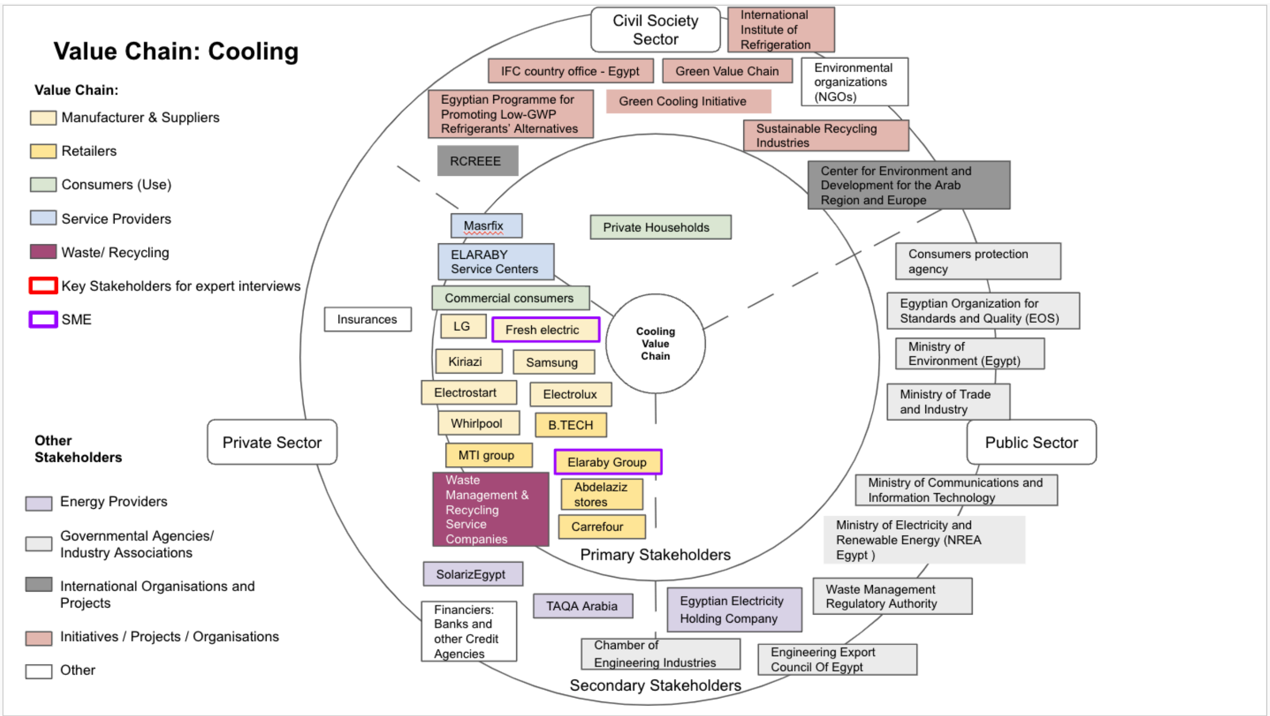

Figure 19 Refrigerator stakeholder mapping