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Water-Energy-Food-Nexus Farming: Upscaling Solutions for Small and Medium-Scale Farms

Impact of the Project and GEBAL's Nexus Farming Models on the Sustainable Development Goals

- EGYPT-

Gebal جبال
— SUSTAINABILITY . AGRICULTURE . LIVELIHOODS —

June 2023

1. Report Highlights

- Water Savings of up to 42.2% per Year
- Savings of up to 5,447.6 Liters of Diesel per Year
- Savings of up to 43,580 EGP for Diesel per Year
- Reduction of CO2 Emissions of up to over 10 Tons per Year
- 296 People Trained

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2. Introduction

Between August 2022 and June 2023, GEBAL carried out the project "Water-Energy-Food-Nexus Farming: Upscaling Solutions for Small and Medium-Scale Farms", co-funded by the European Union and the German BMZ and implemented by GIZ. The project included a targeted assessment of the impact of nexus farming solutions, based on data collection and financial feasibility studies carried out for two nexus farming greenhouses GEBAL had set up in Dandara and Esna, Upper Egypt, as well as in the Oasis of El Heiz in Egypt's Western Desert. Through a series of interactive dialogues and workshops, GEBAL assessed what different stakeholder groups need to support the replication of nexus farming solutions across Egypt, and how an enabling political, social, cultural, economic, and financial environment can be created that assists farmers with a large-scale uptake of nexus farming solutions. The project also entailed the delivery of training courses for trainers, farmers, researchers, and extension agents.

This report provides an overview of the sustainability impact of this project. The report is organized in sections that respond to selected Sustainable Development Goals.

3. The Need for Nexus Farming

Egypt is facing a serious future challenge: How will we satisfy the food and nutrition needs of a rapidly growing population with limited land resources and dwindling water resources? In order to address this problem, we need to develop innovative food production solutions that make use of every input and output, that are based on circular models of resource use, and that boost the production of food for every single drop of water. To phase out the use of fossil fuels, such systems should be run entirely by renewable energy, thus cutting down on emissions and pollution and saving local farmers large amounts of money. Saving money means raising monthly incomes for rural families and thus positively affecting the health and quality of life of farmer families.

Many of Egypt's rural areas still lack basic public services related to electricity, water and sewage, while existing services are often based on the combustion of fossil fuels. Most small farmers in Egypt still practice flood irrigation and use Diesel or electricity-powered pumps to pump water for irrigation - either from canals or from aquifers onto their fields. The use of fossil fuels for pumping means that agricultural irrigation is intrinsically connected to the emission of greenhouse gasses. Rising Diesel prices are making it more and more difficult for farmers to irrigate, having led many Egyptian farmers to either reduce the area of their irrigated lands or to abandon farming altogether. Moreover, flood irrigation is a very water-inefficient irrigation practice, particularly considering that Egypt is a water-scarce country that is expected to fall below the threshold of absolute water scarcity within the next few years. Agriculture consumes over 80% of the country's freshwater. Food security is another challenge, and to feed a population of 104 million that grows by an extra million every 6-10 months, the country imports much of its food. Egypt derives over 50% of its wheat from outside the country and, formerly the corn chamber of the Roman Empire, has become the largest wheat importer in the world. Food imports create a dependency on the world food market and make Egypt vulnerable to price fluctuations.

While successful models for sustainable farming exist, there still needs to be a large-scale uptake of sustainable and nexus farming techniques across the country. As the majority of Egyptian farmers work on small to medium-scale farms (between ¼ acre and 20 acres), this represents a challenge, as farmers, who already struggle with water scarcity, climate change impacts, rising prices, and increasingly competitive farming conditions, often lack the money, capacity, and access to information and technology required to replicate such successful models. It is clear that the kind of investment that is needed to convert the majority of Egypt's farms to sustainable, climate-smart farms cannot be delivered by one entity alone.

As Egypt is committed to achieving the Sustainable Development Goals by 2030 and is also a signatory to the Paris Agreement on Climate Change, community development solutions in the fields of water and energy provision have to be sustainable as well as low on carbon emissions. As the concept of sustainable development integrates environmental, economic, and social dimensions, community development solutions that are to be sustainable cannot only rely on technical solutions. They also need to consider environmental impacts, poverty alleviation, social and gender equality, long-term affordability, job creation for both genders, and capacity and know-how for sustainable operation and management.

4. GEBAL's Nexus Farming Models

In order to test innovative farming solutions on the ground, it is critical to implement models that cannot only be assessed in operation, but that can also function as training spaces that offer farmers opportunities to see such innovative models first hand. Between 2017 and 2022, GEBAL installed model greenhouses in the oasis of El Heiz in Egypt's Western Desert, as well as in Dandara and Esna in Upper Egypt. These two nexus greenhouses integrate sustainable food production, water use, and energy production in one combined solution. They are both based on a circular model of resource use, are fully solar/powered, and integrate fish and crop production for a more intensive and healthier production of food. The models are based on two different designs:

3.1 Solar-Powered Shade House

The shade house is a more affordable structure that is based on locally available materials and easy to install. The shade house is a standard greenhouse (9x30m) consisting of a steel structure and a shade net. The modifications that GEBAL made was the inclusion of a fishpond that enables a circular production process wherein water from the fish tank is used for the irrigation of vegetables grown in the greenhouse. For that purpose, a portion of the shade house was designated to house a small fishpond. The fishpond consists of a polyethylene sheet and can house up to X fish. Figure 1 shows a sketch of the design of the nexus greenhouses and Figure 2 is a picture of the shade house model installed and tested in the oasis of El Heiz in Egypt's Western Desert.

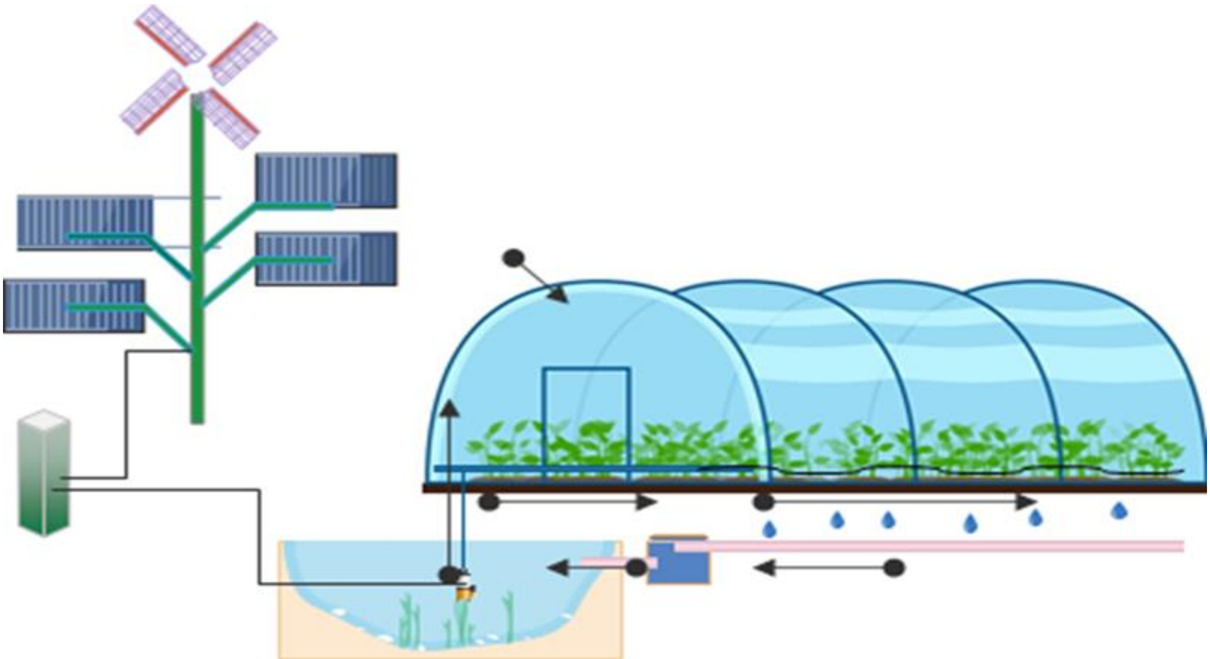

Figure 1: Basic sketch of the nexus greenhouse design – including a solar system, a fishpond, and crop production with drip irrigation system.

Figure 2: Picture of the shade house model installed in El Heiz oasis with solar panels showing on the left, the shorter section of the L-shaped greenhouse housing the fishpond, the crop production housed in the longer part of the shade house.

3.2 Solar-Powered Climate Controlled Greenhouse

The solar-powered, climate-controlled greenhouse models were established on an area of 640m² (16mx40m) each and are covered with 200µm plastic sheets. The greenhouse structure is a stable construction of galvanized steel pipes, built on a concrete baseplate. The greenhouse can be accessed through a slide door and has a working area for diverse agricultural operations. For an optimal climate for the plants, the greenhouse is equipped with a cooling system and a climate control unit. This cooling system is based on the principle of evaporative cooling, based on water. Air is sucked out of the greenhouse on one side of the greenhouse with the help of fans, which, in turn, means that new air is sucked into the greenhouse on the opposite side. This air passes through a cardboard pad that can be wetted and thus ensure that the air that enters the greenhouse is cooler.

The cooling system includes 4 exhaust-fans, one 1.5 hp motor and pad-cooling materials which are connected to a water pump to drop water on the cooling material. These water droplets are then collected in a tank and circulated back to the cooling system. Two fans are installed in the middle of the greenhouse for better air-circulation and climate regulation. The climate control unit includes sensors for temperature and relative humidity that are connected to a controller regulating the exhaust-fans and the cooling system according to the needs of the plants. Water for the drip-irrigation system and the cooling system are pumped up from the Nile. The irrigation water is stored in a 30m³ fishpond, while the cooling water for the pads is stored in a water tank. This fishpond houses 3,000 fish and is aerated by a water shower system to adjust the oxygen levels for the fish. All pumps, motors and systems are operated by solar energy.

Figure 3 shows the climate-controlled greenhouse model installed in Dandara and Esna in Upper Egypt, with larger solar panels showing at the front of the greenhouse. Table 1 summarises the technical specificationsf of the two different models presented here.

Figure 3: Climate-controlled greenhouse in Dandara, Governorate of Qena.

Table 1: Comparison of technical specs of the two nexus greenhouse solutions

Specifications	Shade House	Climate-Controlled Greenhouse
Dimensions	8m x 30 m (240m²)	16m x 40m (640m²)
Construction	Galvanized steel pipes Shade net	Concrete Baseplate Galvanized steel pipes 200µm Plastic Sheets
Off Grid Power Supply	1.4 kW PV modules + 3 kW inverter (drive) + 2 batteries (200 Amp, 12 Volt)	15 kW PV modules + 15 kW Inverter (Drive)
Cooling System	None	4 exhaust fans + 2 circulating fans + 1.5 hp motor + pad-cooling material
Climate Control	Only shading sheet	Temperature Sensors + Relative Humidity Sensors + Controller
Plants Grown During Test Phase	Green Peppers	Green Peppers
Fishpond	With aeration system shower on the top)	30m³ with aeration system (showers on the side)

5. Introduction to the Nexus Farming Testing Locations

This brief overview of the two locations in which GEBAL's nexus greenhouse models were installed and tested, and where research was carried out as part of the present project provides some environmental, social, and economic context for the operation and role of the greenhouses in local agricultural livelihoods. Ensuring a sustainable uptake of nexus farming in Egypt goes well beyond the development of technical models. It also includes the adjustment of nexus farming solutions to local needs and conditions.

4.1 Dandara, Qena Governorate and Esna, Luxor Governorate, Upper Egypt

Upper Egypt is among the Egyptian regions suffering the most from poverty. According to IFAD (2019), poverty "remains a major challenge, especially in rural Upper Egypt, where poverty rates reach almost 60 per cent". At the same time, Upper Egyptian governorates still lack complete coverage of public services, for example regarding sewage water management and treatment. Qena is being tackled as one of the country's poorest governorates as part of the government's Upper Egypt Local Development Program, which was started in 2019. We propose two project locations in Upper Egypt, one in Qena and one in Luxor Governorate, where target villages will be accessed through the NGO Dandara Cultural Center, which is based in Dandara, Qena.

The Dandara Cultural Center (DCC) is an NGO with its center in Dandara that operates all across Upper Egypt between Dandara and Nuba. The NGO has several branches, including the Dandara Development Center (DDC), which focuses on generating economic development in Upper Egypt. The DDC has been particularly active in creating job and income opportunities for women and youth, with several regionally famous projects including jewellery making workshops for women, and a factory that makes local pickles. Both the DCC and the DDC offer substantive training measures for farmers, youth, women, and children. The centers have been funded by multiple donors, including GIZ and USAID, and are very experienced with implementing donor-funded projects.

The NGO owns a guesthouse right on the Nile in Dandara where it conducts training programs and community meetings. The NGO is extremely well connected with local families, especially with less well-off households that may be struggling with income, job opportunities or the lack of knowledge and capacity. GEBAL's team members have worked with the NGO on multiple projects, including the implementation of waste management systems and the development of green curricula for local daycare centers. The DCC has been running English language and business programs for local residents in partnership with AUC's School of Continuing Education for years. Female members are strongly represented at all of the NGOs events and have a strong voice in shaping its projects and activities.

According to the Dandara Development Center, this project will help farmers in Upper Egypt acquire the skills, capabilities and capabilities to invest in clean and renewable energy and to introduce unconventional agriculture based on agricultural manufacturing industries and value chains, working on economic development and increasing farm income to provide a safe and stable life in the governorates of Qena and Luxor. The project works to provide an appropriate environment in which a great deal of gender equality can be provided by providing an opportunity for the participation of girls and women of up to 35%. The Dandara Development Center would prepare and coordinate the project by providing the target group, project implementation sites and the volunteer team, providing the required technical support and assistance in monitoring and evaluation activities, programs and projects and documenting all activities and programs.

The proposed village is a part of Dandara, which has 100,000 inhabitants. Farmers in Dandara grow bananas, wheat, corn, clover, and vegetables. Local families suffer from low incomes, unemployment, and a lack of local employment opportunities, as well as problems in the marketing process of agricultural products. The integrated greenhouse will be overseen by the NGO Dandara Development Center, which will select a committee to operate and maintain the greenhouse. Seedlings and plants cultivated in the greenhouse could be marketed to companies specialized in medicinal plants and vegetables in Beni Suef and Giza. These companies, who are already partnering with farmers in Dandra, guarantee local operators a fixed price and send their engineers for technical support, thus facilitating a more sustainable future maintenance strategy. The chicken incubator system would be run by a group of local women, while the project would be overseen and facilitated by the Dandara Development Center.

In Esna, Luxor Governorate, where the Dandara Development Center also has a branch, the target village would be Farsia, a village that is inhabited by 20,000 people. Local farmers grow sugarcane, wheat, corn, vegetables, clover, tomatoes and fish. As in Dandara, unemployment is high, employment scarce and marketing opportunities limited. For this reason, it is important to add value to local crops. The projects will be operated and managed in the same way as in Dandara, with the NGO overseeing the project and a selected committee working on the direct operation and maintenance of the system.

4.2 El Heiz Oasis, Western Desert of Egypt

El Heiz is a small oasis located 400 km to the southwest of Cairo. The oasis is home to around 5,000 inhabitants, housed in scattered villages of a few hundred inhabitants each. Local livelihoods depend on farming, with dates being by far the most important crop, accounting for around 70% of family incomes. Farmers also grow watermelons, wheat (mostly for home consumption), some vegetables, as well as clover and maize for animal production. With the nearest town, the oasis of Bahariya, located 40 km away, El Heiz is a very remote village. Not connected to the national electricity grid, which ends in Bahariya, El Heiz receives its power from local, Diesel-powered generators that run only 6 hours per day, from 6 pm to 12 am. The only water source in El Heiz is the Nubian Sandstone Aquifer, a finite aquifer of fossil water that is between 200,000 and 1 million years old. Under current climatic conditions, this aquifer receives very little recharge, which is why it is internationally classified as finite. Water is pumped up from depths of between 150 and 1,200 meters. As artesian wells ran dry over the past two decade, farmers do need a pump to access this water. Many pumps are still operated by Diesel generator. However, solar pumping is becoming more and more popular in the oasis, especially given the rising Diesel prices. The old lands, mainly date palm forests under which additional crops are being grown, are irrigated by flood irrigation. Here, local families share land that is irrigated by a large well operated by the government. Every family has access to irrigation water one day per week and uses this day to flood their fields around the well. Newly developed lands around El Heiz are irrigated by privately owned wells that are all solar-powered. The younger farmers who drive these land expansions also experiment with drip and sprinkler irrigation, although some of this new land is also irrigated by flood irrigation.

Due to the oasis's location in the middle of the desert, El Heiz farmers are far away from markets. This means agricultural inputs such as fertilizers and pesticides, are brought in from Cairo and thus comparatively expensive. Moreover, selling agricultural produce is a challenge and requires either the transportation to markets in Cairo or the selling to vendors who come into the oasis, but who also determine the price. Local agricultural markets are limited, especially for higher end crops, although local farmers do sell on the markets in Bahariya and Farafra oases.

6. Nexus Farming and the Sustainable Development Goals

The nexus farming models were designed to advance more sustainable and climate-smart production methods for Egyptian farmers. Their designs, which enhance food production while encouraging a more sustainable use of resources while also reducing carbon emissions, bear the potential to transform food production systems in Egypt. Moreover, they represent an opportunity to encourage climate-smart agriculture in a country that is vulnerable to climate change impacts. The successful replication of such models can help Egypt achieve the Sustainable Development Goals (SDGs) and Egypt's Agenda 2030, while also helping the country comply with the Paris Agreement. As the host of the COP27 Conference in Sharm-El-Sheikh, Egypt has placed stress on meeting its greenhouse gas emissions reduction goals.

GEBAL's Nexus Farming Models are connected to several SDGs. The focus on this resort will be placed on the following SDGs:

SDG 1 - No Poverty
SDG 2 - Zero Hunger
SDG 3 - Good Health and Well-Being
SDG 4 - Quality Education
SDG 5 - Gender Equality
SDG 6 - Clean Water and Sanitation
SDG 7 - Clean and Affordable Energy

SDG 8 - Decent Work and Economic Growth
SDG 11 - Sustainable Cities and Communities
SDG 12 - Responsible Consumption and Production
SDG 13 - Climate Action
SDG 16 - Partnerships for the Goals

This report assesses the impact of the GEBAL nexus greenhouse models, as an example of nexus farming in Egypt, on different SDGs. The report also includes the activities conducted of the project "Water-Energy-Food-Nexus Farming: Upscaling Solutions for Small and Medium-Scale Farms".

In order to assess the nexus farming models' performance in relation to different SDGs, as well as the general performance of the two greenhouses, data was collected in two of the greenhouses - the model in El Heiz and the model in Dandara. The data collection entailed data on:

1. Water consumption (water meters were installed for in and out)
2. Electricity consumption
3. Fertilizer consumption and cost
4. Pesticide consumption and cost
5. Temperature inside the greenhouse
6. Water temperature in the fish pond
7. Ph value of the fish pond water
8. Oxygen level of the fish pond water
9. EC (electric conductivity) of the fish pond water
10. Salinity of the fish pond water
11. Amount and cost of fish feed

This data was used to calculate the total productivity and economic performance of the greenhouses, as well as their environmental performance. Interviews with the farm operators led to further insights into the social impacts of the greenhouses.

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SDG 1: No Poverty

SDG 1 entails the eradication of poverty by 2030. The nexus greenhouses designed by GEBAL have the potential to increase the productivity, particularly of small agricultural areas. Especially along the Nile, the size of agricultural areas has been becoming smaller over the past decades due to fragmentation. The Islamic inheritance system foresees that land is divided among the children of a deceased person, a process that over generations results in farm areas that in the Nile Delta reach sizes of a quarter of an acre. These land sizes are too small to sustain the income of a farming family. It is therefore critical that farmers can make the most out of these small land plots.

In order to assess whether nexus farming models are financially feasible for small and medium-sized farms, and in how far they can raise farmers' incomes, three feasibility studies were carried out as part of this project:

1. **A GEBAL-internal financial feasibility study, carried out by a consultant hired by GEBAL, in partnership with GEBAL's technical staff**
2. **An independent feasibility study for GEBAL's two nexus greenhouse models carried out for GEBAL by SME Consulting**
3. **An independent feasibility study for an open farm nexus farming model designed and implemented by GEBAL in Egypt's Nile Delta, carried out for GEBAL by SME Consulting**

1. GEBAL-Internal Financial Feasibility Study

The project also entailed the production of a GEBAL-internal economic feasibility study that included the production of detailed business plans and models for the different greenhouse models. This assessment was critical in the context of determining whether the nexus greenhouse models represent viable and sustainable investment opportunities and can potentially enhance farmers' incomes in the medium to long term (within 5 to 10 years). The feasibility study included a calculation of payback durations and return on investment under different financing scenarios that included:

4. Equity Financing
5. Combined Equity and Debt Financing
6. Combined Equity, Debt and Grant Financing
7. Debt Financing
8. Grant Financing
9. Combined Grant and Debt Financing
10. Combined Grant and Equity Financing

The study shows that both greenhouse models can be made economically viable and have the potential to improve farmers' incomes. They can also both breakeven and generate salary earnings from the first year of operation, even if financed completely by debt. In heavy debt financing, the bulk of revenues is eaten up by loan repayments and practically earnings will come from self-employment salaries. This treats the family farm greenhouse, however, as a business unit. In such a case, a user-friendly accounting instrument needs to be in place for farmers to ensure that for the payback duration of the project they are fulfilling all the necessary payments, breaking even, and not challenged by hidden unaccounted for costs.

The feasibility study assumes that greenhouse output is demanded by an accessible market, and at a price that motivates a sustained production. Testing the product-market fit is essential to the sustenance of production because the cost of producing in greenhouses is substantially higher than on regular open fields (both operating and initial costs are higher). Retail chains present a market for this upgraded quality produce, and domestically supplying these foods ensures their freshness as well, making this the domestic marketing channel with the most financially rewarding potential for greenhouse output. Yet, there are limitations for individual farmers because a small farm unit (even with consistent output schedules) does not provide enough supply volumes to fill the shelves and achieve brand recognition amongst retail shoppers. This implies that a cooperative for collective marketing might be essential for the success of greenhouses, whereby a large group of small units consolidate their output under one brand name and supply retailers with a quality-consistent product. Meaning also that a quality assurance function would need to be run by this marketing cooperative, along with packaging and logistical frameworks. The alternative is to only enable farmers to produce more output per square-meter, at an improved quality, and leave them to continue selling in the existing domestic channels run by wholesale traders and markets. This is a lower paying channel, but it also requires less rigid standards and is already accessible to farmers, making it a safer and more familiar selling channel.

1. Shade House Model

Table 2 shows the results of the financial feasibility study for a shade house model, based on the one installed in El Heiz. Figure 4 presents the results of the financial calculations as a graphic.

Table 2: Shade house model (based on El Heiz model) based on farmgate sales and a large, 1,440 square-meter greenhouse (the size of the original model was increased to maximize profitability – the assumption here is that a group of farmers would work together on operating the greenhouse

Type of Financing	Debt Amortization	Yearly Cost of Equity based on a 9% inflation rate	Payback Period	**Realized Profit during first ten years (At NPV)**	**Year 11 Owards: Realized Profit after initial capital costs are covered (At NPV) EGP 153,000**
100% Equity	0	23,996	10 Years	35,982	59,978
100% Debt	27,816	0	10 Years	32,162	59,978
100% Grant	0	0	0	59,978	59,978
50% Grant 50% Equity	0	11998	10 Years	47,980	59,978
50% Grant 50% Debt	13908	0	10 Years	46,070	59,978
50% Equity 50% Debt	13,908	11,998	10 Years	34,072	59,978
Equal weight to all three; 33%, Grant, Equity and Debt	9272	7998.666667	10 Years	42,707	59,978
Low interest Development Debt Financing (5% i-rate) ↓			10 Years		0
100% Debt	20,500	0	10 Years	39,478	59,978
Equal weight to all three; 33%, Grant, Equity and Debt	6833.333333	7,999	10 Years	45,146	59,978
50% Low interest Debt and 50% Grant	10,250	0	10 Years	49,728	59,978
50% low interest debt and 50% Equity	10,250	11998	10 Years	37,730	59,978

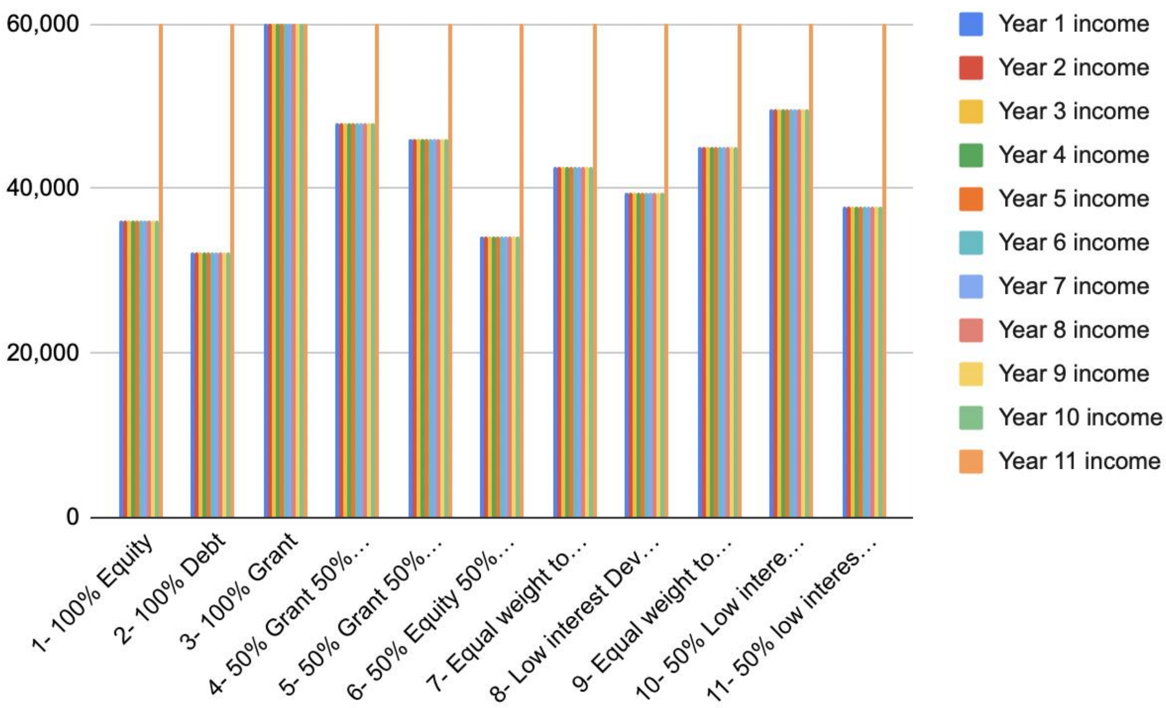

Figure 4: Financial feasibility of shade house model - farmgate sales: large 1,440 square-meter greenhouse.

Table 3 shows the same model for a retail sales scenario, while Figure 5 is presenting the result in the format of a graphic.

Table 3: Shade house model (based on El Heiz model) based on retail sales and a large, 1,440 square-meter greenhouse (the size of the original model was increased to maximize profitability – the assumption here is that a group of farmers would work together on operating the greenhouse

	Type of Financing	Debt Amortization	Yearly Cost of Equity based on a 9% inflation rate	Payback Period	**Realized Profit during first ten years (At NPV)**	**Year 11 Owards: Realized Profit after initial capital costs are covered (At NPV) EGP 153,000**
1	**100% Equity**	0	23,996	10 Years	132,232	156,228
2	**100% Debt**	27,816	0	10 Years	128,412	156,228
3	**100% Grant**	0	0	0	156,228	156,228
4	**50% Grant 50% Equity**	0	11998	10 Years	144,230	156,228
5	**50% Grant 50% Debt**	13908	0	10 Years	142,320	156,228
6	**50% Equity 50% Debt**	13,908	11,998	10 Years	130,322	156,228
7	**Equal weight to all three; 33%, Grant, Equity and Debt**	9272	7998.666667	10 Years	138,957	156,228
	Low interest Development Debt Financing (5% i-rate) ↓			10 Years		0
8	**100% Debt**	20,500	0	10 Years	135,728	156,228
9	**Equal weight to all three; 33%, Grant, Equity and Debt**	6833.333333	7,999	10 Years	141,396	156,228
10	**50% Low interest Debt and 50% Grant**	10,250	0	10 Years	145,978	156,228
11	**50% low interest debt and 50% Equity**	10,250	11998	10 Years	133,980	156,228

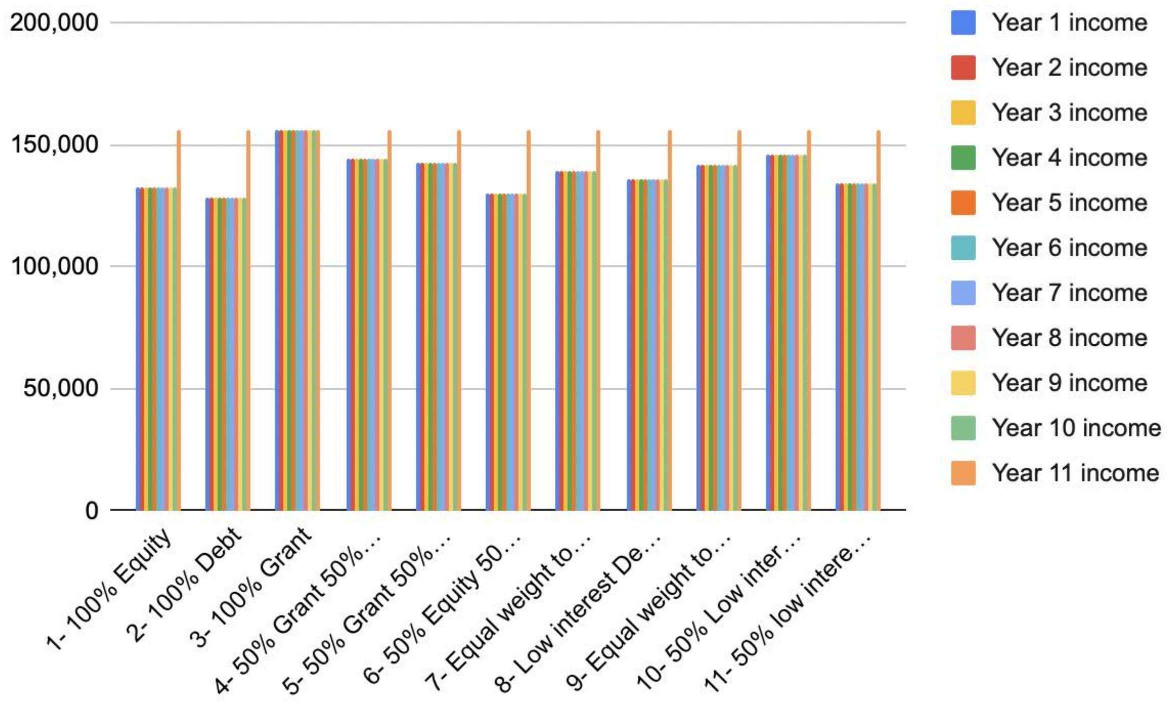

Figure 5: Financial feasibility of shade house model - retail sales: large 1,440 square-meter greenhouse.

2. Climate-Controlled Greenhouse Model

Table 4 shows the financial feasibility calculations for a climate-controlled greenhouse based on the model installed in Dandara, Upper Egypt. Figure 6 presents the same results graphically.

Table 4: Climate-controlled greenhouse model (based on Dandara model) based on farmgate sales

	Type of Financing	Debt Amortization	Yearly Cost of Equity based on a 9% inflation rate	Payback Period	**Realized Profit during first ten years (At NPV)**	**Year 11 Owards: Realized Profit after initial capital costs are covered (At NPV)**
1	**100% Equity**	0	71,833	10 Years	35,537	107,370
2	**100% Debt**	83266	0	10 Years	24,104	107,370
3	**100% Grant**	0	0	0	107,370	107,370
4	**50% Grant 50% Equity**	0	35916.5	10 Years	71,454	107,370
5	**50% Grant 50% Debt**	41633	0	10 Years	65,737	107,370
6	**50% Equity 50% Debt**	41,633	35,917	10 Years	29,821	107,370
7	**Equal weight to all three; 33%, Grant, Equity and Debt**	27755.33333	23944.33333	10 Years	55670.33333	107,370
	Low interest Development Debt Financing (5% i-rate) ↓			10 Years		
8	**100% Debt**	65000	0	10 Years	42370	107,370
9	**Equal weight to all three; 33%, Grant, Equity and Debt**	22000	24,000	10 Years	61,370	107,370
10	**50% Low interest Debt and 50% Grant**	32,500	0	10 Years	74,870	107,370
11	**50% low interest debt and 50% Equity**	32,500	35916.5	10 Years	38,954	107,370

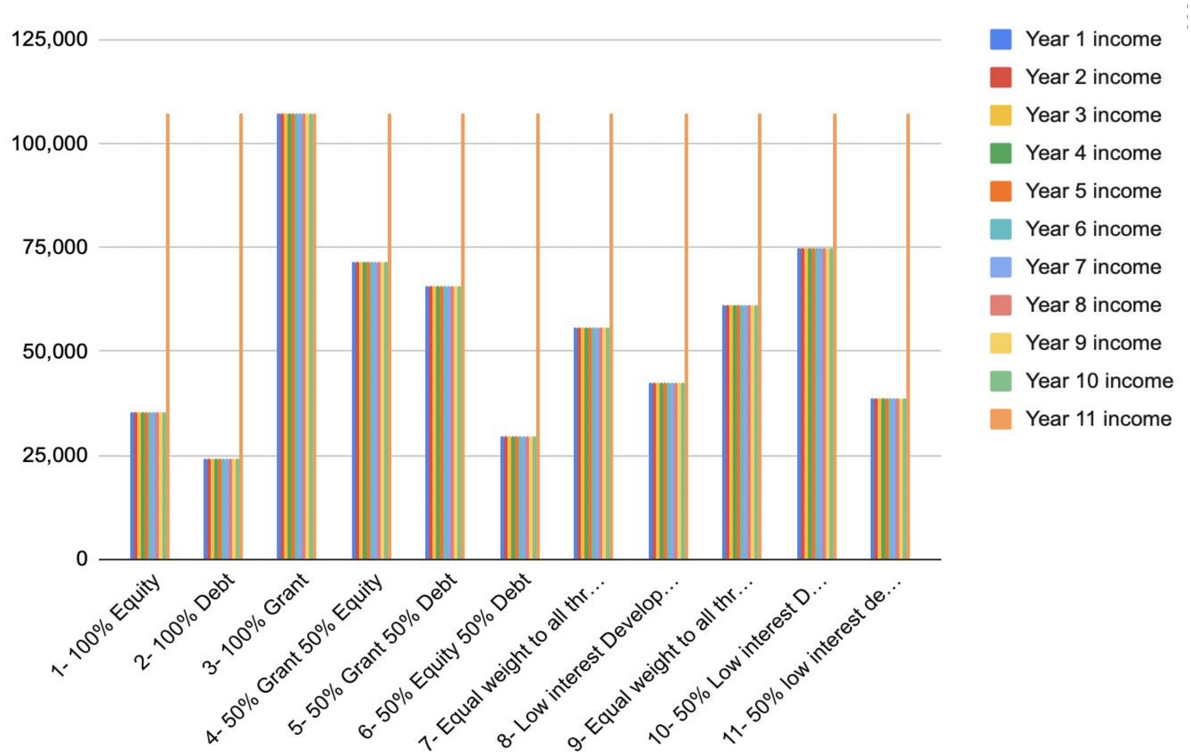

Figure 6: Financial feasibility study of climate-controlled greenhouse model, farmgate sales.

Table 5 and Figure 7 shows the results for the same greenhouse model but based on retail sales.

Table 5: Climate-controlled greenhouse model (based on Dandara model) based on retail sales

Type of Financing	Debt Amortization	Yearly Cost of Equity based on a 9% inflation rate	Payback Period	**Realized Profit during first ten years (At NPV)**	**Year 11 Owards: Realized Profit after initial capital costs are covered (At NPV) EGP 153,000**
100% Equity	0	71,833	10 Years	117,037	188,870
100% Debt	83266	0	10 Years	105,604	188,870
100% Grant	0	0	0	188,870	188,870
50% Grant 50% Equity	0	35916.5	10 Years	152,954	188,870
50% Grant 50% Debt	41633	0	10 Years	147,237	188,870
50% Equity 50% Debt	41,633	35,917	10 Years	111,321	188,870
Equal weight to all three; 33%, Grant, Equity and Debt	27755.33333	23944.33333	10 Years	137,170	188,870
Low interest Development Debt Financing (5% i-rate) ↓			10 Years		0
100% Debt	65000	0	10 Years	123,870	188,870
Equal weight to all three; 33%, Grant, Equity and Debt	21666.66667	23,944	10 Years	143,259	188,870
50% Low interest Debt and 50% Grant	32,500	0	10 Years	156,370	188,870
50% low interest debt and 50% Equity	32,500	35916.5	10 Years	120,454	188,870

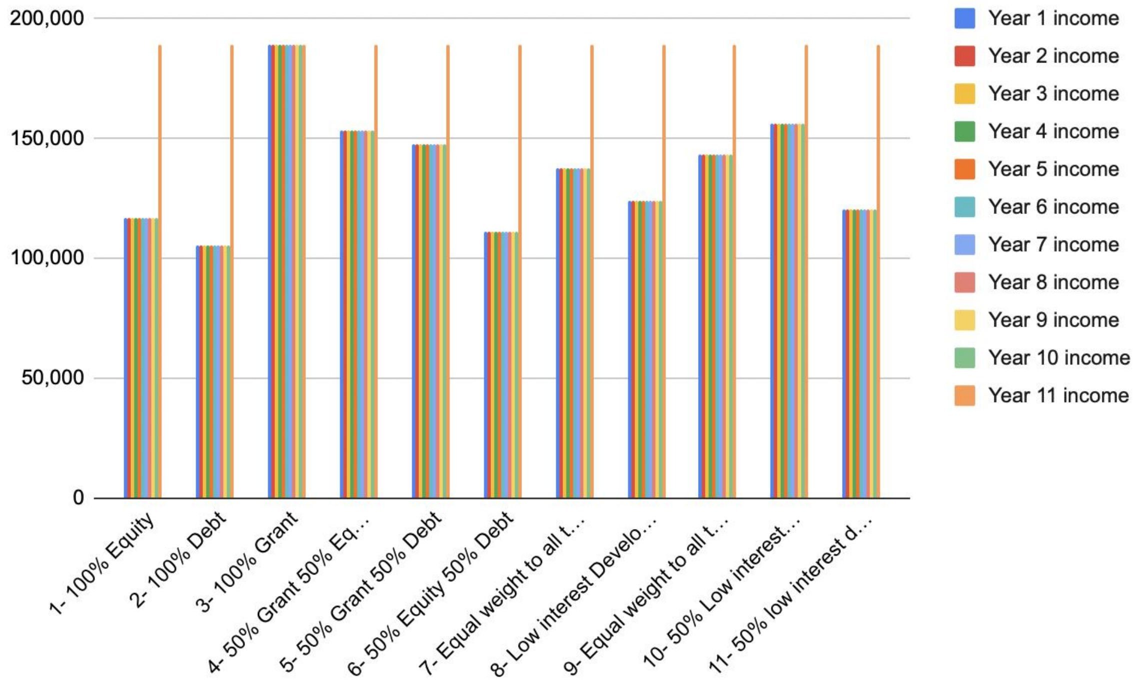

Figure 7: Financial feasibility study of climate-controlled greenhouse model, farmgate sales.

2. External Financial Feasibility Studies

In addition to carrying out an internal financial feasibility study, an independent feasibility study conducted for GEBAL by SME Consulting in Egypt in June 2023 concludes that greenhouse-based nexus farming solutions have the potential to raise farmers' incomes. It is critical to mention that between the internal and external financial feasibility studies, the Egyptian Pound experienced considerable devaluation against the US Dollar, meaning that the prices for the greenhouse infrastructure had increased significantly between the two studies.

2.1 Shade House Model

The following assumptions drove the assessment:

The project has an initial investment cost of approximately 1,200,000 EGP, which includes working capital. The financing for the project consists of 31.8% equity and 68.12% debt.

The target capital 370,000 EGP, while the targeted debt portion is 790,000 EGP, including financing costs during the implementation period.

The debt tenor is estimated for 10 years with an interest rate of 5%.
There is a transportation expense of 4,000 EGP/ year and a monthly salary of 3,000 EGP for an engineer.
The expected cucumber productivity starts from 13 kg/sqm/year, however, to achieve the minimum profitability the farmer needs to produce 19 Kg/sqm/year and at price 17,500 EGP/Kg, at least.
Selling price is 17.5 EGP / kg

Based on these assumptions, the capital budgeting indicators are as follows:

Average rate of return on invested capital (ROI): 233%.
Internal rate of return (IRR): 15% (influenced by the high interest rate)
The investment cost recovery period (payback period) is approximately 7 years.
Net present value (NPV): 10,959 EGP

2. Climate-Controlled Greenhouse Model

The following assumptions drove the assessment:

The project has an initial investment cost of approximately 1,400,000 EGP, which includes working capital.
The financing for the project consists of 27% equity and 73% debt.
The target capital 378,000 EGP, while the targeted debt portion is 1,022,000 EGP, including financing costs during the implementation period.
The debt tenor is an estimated 10 years with an interest rate of 5%.
For the greenhouse operations, the farming land covers an area of 640 m^2.
The cultivated crop is cucumber

There is a transportation expense of 4,000 EGP/ year and a monthly salary of 3,000 EGP for an engineer.
It is assumed that the land is owned by the farmer, and its value increases by 10% annually.
After 10 years, the estimated salvage value of the land reaches 959,685 EGP.

The retail selling price for the crop is calculated for 3 scenarios:

At 16 EGP/Kg with a productivity rate of 23 kg/sqm/year
At 17.5 EGP/Kg with a productivity rate of 21 kg/sqm/year.
At 18.75 EGP/Kg with a productivity rate of 21 kg/sqm/year.

*The retail selling represents the main selling scenario (100% of the quantity).

Based on these three scenarios, the financial calculations are as follows:

Capital budgeting indictors for selling at price **16 EGP/kg**:

Average rate of return on invested capital (ROI): 215.66%.
Internal rate of return (IRR): 14.4% (influenced by the high interest rate)
The investment cost recovery period (payback period) is approximately 7 years.
The net present value (NPV) amounts to 24,098 EGP.

Capital budgeting indictors for selling at price **17.5 EGP/kg**:

Average rate of return on invested capital (ROI): 215.66%.
Internal rate of return (IRR): 14.4% (influenced by the high interest rate)
The investment cost recovery period (payback period) is approximately 7 years.
The net present value (NPV) amounts to 24,098 EGP.

Capital budgeting indictors for selling at price **18.5 EGP/kg**:

Average rate of return on invested capital (ROI): 228.00%.
Internal rate of return (IRR): 15.7% (influenced by the high interest rate)
The investment cost recovery period (payback period) is approximately 7 years.
The net present value (NPV) amounts to 115,226 EGP.

3. Open Field Model

The nexus open field model using nexus farming differs from the greenhouse in that it integrates fish and cucumber cultivation on an open field, without the presence of climate- controlled greenhouses or greenhouse covered with shading nets. The system has three components:

1. Solar system
2. Irrigation system
3. Fish tank system

The following assumptions drove the assessment:

The project has an initial investment cost of approximately 1,050,500 EGP, which includes working capital.
The financing for the project consists of 35.22% equity and 64.78% debt.
The target capital 370,000 EGP, while the targeted debt portion is 680,500 EGP, including financing costs during the implementation period.
The debt tenor is an estimated 10 years with an interest rate of 5%.
The cultivated crop is cucumber.
The expected cucumber productivity starts from 13 kg/sqm/year, however, to achieve the minimum profitability the farmer needs to produce 16.5 kg/sqm/year and at price 18.75 EGP/kg, at least.

Same operations inputs in the shading model apply to the nexus open field farming except for the shading nets and the related infrastructure to the shading nets model.

The capital budgeting indicators for selling at price **18.75 EGP/Kg** are as follows:

Average rate of return on invested capital (ROI): 241.63%.

Internal rate of return (IRR): 15.3% (influenced by the high interest rate)

The investment cost recovery period (payback period) is approximately 7 years.

The net present value (NPV) amounts to 12,692 EGP.

3. Income Enhancement through WEF Nexus Farming

Whether or not such an environmentally considerate upgrade in farmers' operations is immediately feasible for short-term analyses will be irrelevant once water and energy shortages deny farmers from the ability to produce at lower than optimal efficiency levels. This means that, once there is a shortage (of water or energy), farmers will be forced to find whatever technological and process upgrades available that can enable them to produce output that is of profitable value in the market. This holds for energy usage and types, water needs, as well as the food's health-related quality and quantities. Hence, converting operations from ones that produce less than optimal food quality and quantities to high quality / high output foods, while using less water in irrigation, and sourcing energy from renewable sources instead of expensive and carbon emitting ones, is an essential matter for being able to stay in business. In other words, it is how farm operations could be sustained.

The sooner this conversion/upgrade happens the better equipped a farm will be for climate, energy markets, water shortages, or resource induced crises. The challenge will be to enable farmers to remain profitable during the early years of operations in an upgraded WEF- Nexus farm. This is especially critical due to the high initial costs of such upgrades, as well as the rise in its operational cost. Hence a market fit feasibility is essential to the generation of cash flows through sales revenues, so that the enhanced quality of food in this new operation finds its financial reward in the market, and higher prices combined with an increased output per square meter generate enough to offset the newly increased costs and generate profits for small family farms.

Our models produce higher output at enhanced quality per square meter. The feasibility studies show an appeal for such output in markets, and a demonstrated willingness to pay premiums for high quality produce. In principle this is promising, and providing farmers access to such technical upgrades will be the first step in advancing their operations. Following that will be providing technical supervision in operation as well as maintenance support to ensure quality control measures remain in place, and to add longevity to the newly acquired farm capital. Finally, enabling farmers to sell all their output at adequate prices will be essential for their farm units' economic durability. Also for those acquiring debt or investing their own savings (equity), such economic success will be vital to realizing adequate returns on investment to pay back debt, and on time, and to regain invested amounts. This requires a consistent cash flow of revenues, as well as a systematic way of separating operational costs from debt repayment amounts and left over profits, an accounting arrangement that might require a separate capacity building program or a specialized unit to do this on behalf of groups of farmers in one region.

However, these WEF-Nexus upgrades (especially the non-climate-controlled models) have the potential of raising incomes through conventional wholesale at farmgate and without a substantial initial investment. The shade house model implemented in El Heiz as well as the open field provide evidence of improvements in water, energy and input usage that also lead to higher profitability per square meter, but at lower initial investment costs and operational costs.

It is advised to group farms regionally through marketing associations that could secure consistent selling contracts for farmers with either whole buyers, distributors and/or retailers while supervising technical and financial processes to ensure quality control and bank or equity repayments without compromising any of these (especially in early repayment years). Associations will also ensure that farmers make incomes from year one either through profits or salaries (as family farms are self-employed, and our models account for labor costs which could be redirected towards family-farm working members instead). Nevertheless, a farmer that borrows or pays out of pocket to upgrade to a cost-effective and affordable WEF-Nexus model, could sustain profitability through farmgate sales, as long as they invest in a small plot and diversify their farm income in early years. Such individual farmers also will be more income-secured through increasing their farms' resilience to climatic, energy, and water (or other resources) crises that are signalled by our environments to be approaching quickly and have had noticeable effects on farmers (extended heat waves, water supply fluctuations, rising pest numbers, poor output, etc.).

SDG2: Zero Hunger

1. Enhancing Food Production through Nexus Farming

The second SDG sets out to end hunger by 2030. Given food insecurity in Egypt, enhancing agricultural productivity while using less land, water, and energy resources is key. To this end, technical innovation and trials that test such innovations on the ground, such as those implemented by GEBAL, are critical for the development and upscaling of more sustainable food production solutions.

Given Egypt's food security situation, it is critical that even the smallest pieces of land produce as much food as possible, but in a sustainable manner that is resource efficient, relies on the use of all resources and waste products, that uses resources in a circular manner, that is water- and energy efficient, as well as climate neutral.

Agricultural productivity in greenhouses is higher than in open field cultivation. Numbers from studies conducted around vary. Trials in Tanzania have shown a 2.4 (Chakraborty and Sethi, 2015) to 3-fold yield of tomato crops produced in greenhouses versus in open field production (Chacha et al., 2023). Trials carried out on cucumber production in greenhouses vs open field in Egypt showed that the cucumber yield obtained from the greenhouse production was five times that of the open field production (Diab et al., 2016).

In the greenhouses in El Heiz and Dandara, vegetables were being grown during the testing phase - green peppers. The initial trials showed that attaining the full production capacity of greenhouse production requires agricultural and technical experience with greenhouse production. Even though the greenhouse operators in Dandara and El Heiz received training from GEBAL's engineers, as well as technical support during multiple field visits, the productivity of the greenhouses remained behind expectations, which also had implications for the profitability of the greenhouse.

2. Results of the Production Trials in El Heiz and Dandara

In the greenhouse in **El Heiz**, the following numbers were recorded during the test period, based on daily data collected between August 1, 2022, and June 30, 2023:

Total Expenses: 5,740 EGP
Total Harvest in kg: 368
Total Revenues from Harvest: 1,861 EGP
Expected Revenues from Selling Fish: 3,500 EGP
TOTAL PROFIT: - 379 EGP

The productivity per square meter for the El Heiz example is 1,6 kg / square meter, which is disappointing. In trial assessments, farmers blamed the poor quality of the soil in the greenhouse, the lack of application of compost before cultivation, as well as the lack of experience with greenhouse farming.

The experiences from El Heiz show that the greenhouse operators overspent on chemical fertilizer and pesticides. This was done partly due to a lack of experience with monitoring plant health based on the natural fertilizer provided by the fishpond. Furthermore, peppers were sold on the local market for prices ranging between 3 EGP / kg (to local traders) and 7 EGP / kg (directly to community members). El Heiz generally lacks the presence of high-end markets, which limit the marketing options for peppers in the area.

In the greenhouse in Dandara, the following numbers were recorded between November 27, 2022, and April 4, 2023:

Total Expenses: 8,350 EGP
Total Harvest in kg: 2,657
Total Revenues from Harvest: 13,615 EGP
Expected Revenues from Selling Fish: 9,000 EGP
TOTAL PROFIT: 14,265 EGP

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Productivity in the greenhouse in Dandara was 4.15 kg per square meter, which is not bad, but still remains behind the capacities of the installed system (which is around 20 kg per square meter). In Dandara, as well, an overapplication on fertilizers and pesticides, a lack of experience with the system, as well as a lack of high-end market access were also identified as shortcomings during post-trial assessments. The trials show that, in order for farmers to be able to achieve the full productivity benefits of their technologies, longer-term training and supervision may be needed.

3. Benefits of Local Farming

The GEBAL greenhouse has an additional benefit in El Heiz. As El Heiz farmers do not grow enough vegetables to sustain the daily diets of all of the oasis's residents, vegetables are purchased from a pickup truck that tours the oasis every two days. This pickup truck is run by someone from Fayoum who obtains the vegetables in Cairo. Ironically, large vegetable farms operated by investors in the new agricultural expansion areas around the oasis transport their harvest to Cairo for sale in the capital. This means that for the residents of El Heiz, vegetables make a way of 400 km before they reach them. They are also fairly expensive and grown in land and water that is more polluted than that found in El Heiz. The nexus greenhouse thus has the potential to increase local vegetable production, making local residents less dependent on vegetables shipped in from Cairo. This has both financial and health benefits.

SDG 3: Good Health and Well-Being

SDG 3, Good Health and Well-Being, is strongly connected to SDGs 1 and 2. Being able to grow vegetables locally has both economic and health benefits. While rural areas are often seen as less vulnerable to food insecurity than urban areas, given that many farmers are able to produce food for their own households, this rule only applies where local vegetable production can meet the local needs. This is not always the case, especially in El Heiz, which due to its remote location in the middle of the desert is located far away from agricultural markets.

Rural families in Upper Egypt and the Western Desert that struggle financially often cut back the purchasing of fruit and vegetables. In supplying their families with food, local residents often cut back on fruit first, which are seen as expensive and non-essential for preparing daily meals for the family. Only then is the purchasing of vegetables for cooking and meal preparation reduced. Poverty can thus have a detrimental effect on the nutrient intake of rural families, particularly children. Research has shown that in Egypt, every fourth child is affected by stunting, and that anemia is another common health problem related to nutrition intake. In El Heiz, which is located very far away from the nearest water body, fish is being brought in from the Delta, usually once a week. This fish is small, expensive, is often frozen, and local consumers often worry about the quality of the water in which the fish was grown. Fish is thus a type of food that is not easy to come by in El Heiz.

GEBAL’s nexus greenhouse gives the residents of El Heiz an opportunity to grow fish locally, which has a potentially advantageous effect on nutrition and health. Fish farming is not something that most farmers are accustomed to producing, but the trial has shown that the local operator of the nexus greenhouse was able to learn and adjust to the fish farming quite quickly. Together with the production of vegetables, the nexus greenhouse improves the availability of healthy food that is locally produced in good soil, using unpolluted water for irrigation and only a bare minimum of fertilizers and pesticides. The circular production system of the nexus greenhouse ensures that fish droppings in the water produce natural fertilizer for the vegetables, meaning that chemical fertilizer is only needed when plants are showing signs of nutrient deficiency, keeping the use of fertilizer to a minimum. This means that the vegetables produced in the nexus greenhouse are healthier and less contaminated than vegetables produced using conventional growing methods.

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SDG 4: Quality Education

1. Training and Capacity Development through the Nexus Farming Project

Access to quality education is limited in Egypt's rural areas. This includes access to information on farming innovations and sustainable farming. Most farmers in Egypt are not familiar with the problems of water scarcity and climate change and are thus not aware of how they can adjust their farming operations to these threats. The farmers who participated in workshops as part of this project complained about their lack of access to agricultural extension and the perceived absence of extension agents in the area.

This project entailed a Training of Trainers program that was designed to familiarize local farmers with the need for nexus farming, as well as with the technicalities of the design, operation, and maintenance of a nexus farming, including its business model. The GEBAL team thus produced training modules on:

- Climate-smart nexus farming in the context of water scarcity, food security, and climate change.
- Basics of greenhouse farming, including information on solar-powered greenhouses, water-efficient irrigation, and farming models based on nutrient circulation.
- Applications of solar energy systems in agricultural practice.
- Integrated Pest Management (IPM)
- Agricultural waste management
- Basics of farm management and the formulation of business models for a nexus greenhouse: planning, SWOT analysis, bookkeeping, and records.

Between August 2022 and June 2023, GEBAL's team offered a total of 6 training session and one online Master Class that were attended by a total of 296 people. The model was based on the training of nexus farming trainers who then carried out nexus farming training with local farmers. The trainers were selected from among teachers from agricultural schools, extension agents, local agricultural engineers, and farmers who are champions in their communities. Table 6 shows a list of courses that were offered with locations and modules:

Table 6: Training sessions offered as part of the project

Name of Course	Location	Date of Delivery	Number of Attendees	Male / Female Ratio
Nexus Farming	Dandara	4 & 6, August, 2022	52 participants	36.5% Females 63.5% Males
Nexus Farming	El Heiz	7 & 8, September 2022	21 participants	9.5% Females 90.5% Males
Business Planning for Nexus Farming	El Heiz	12th of October 2022	20 participants	30% Females 70% Males
Business Planning for Nexus Farming	Dandara	27th of October 2022	22 participants	37.5% Females 62.5% Males
Nexus Farming in Policymaking and Nexus Farming Business Models	Cairo	12th of June 2023	11 participants	36% Females 64% Males
Nexus Farming	Kafr El Sheikh	15th of June 2023	10 participants	100% Males
Water Energy Food Nexus Winter Master Class	Internet	15th June 2023	160	

In the training sessions carried out in El Heiz and Dandara, around two thirds of training participants had an agricultural background, whereas one third did not have an agricultural background.

The project thus helped expose rural farmers in Dandara, Esna, and El Heiz to the topic of sustainable, climate-smart nexus farming. The trainers who have been trained as part of this project have not only gone through a series of training that has sensitized them to the importance of sustainable farming but have also obtained the skills and materials to deliver training on nexus farming as part of their usual training jobs. More so, GEBAL's training approach entailed that these trainers practiced the delivery of the new training modules in the local community, thus exposing many local farmers to the idea of nexus farming.

The results of the agricultural trials show that much more in-depth training and on-ground support is needed as farmers switch from open field to greenhouse production. However, the trial operators reported that the few months of trial provided them with valuable knowledge in fish production, which they had previously been largely unfamiliar with.

SDG 5: Gender Equality

1. Engagement of Women in Nexus Farming and Project Activities

Farming in Egypt is a gendered process. GEBAL's nexus greenhouse has the potential to foster gender equality and women's empowerment in local communities. Women's involvement in farming is often limited in Egypt's rural areas, as women are not supposed to work much outside the house. Also, agricultural tasks usually underlie a strong gender segregation of labor. Men are usually responsible for irrigation and field preparation, while women may help with the harvest, process and sort harvested products at home, and tend to the rearing of poultry and small ruminants around the household. In the two three test areas, gender segregation is most pronounced in El Heiz oasis, which is marked by Bedouin culture. In Upper Egypt, women are more present and vocal, and are seen more often outside the household. Despite this, the decision-making on farms is strongly in the hands of men, in all three communities.

GEBAL has assessed the gendered experience of operating a nexus greenhouse and the potential impact of the greenhouse on more gender equality in the farming process. The first opportunity for the engagement of women in local agricultural production was pointed out by the local greenhouse operator in Dandara. He noted that the protected environment the nexus greenhouse provided represented a chance for women to become more actively engaged in farming practices without having to work outdoors in an open area. In the interview he argued that the control and maintenance tasks in the greenhouse are much easier and more conducive to the engagement of women than farming tasks on an open field, while the protected environment of the greenhouse created a higher level of cultural acceptance. He thus proposed the creation of an all women-led greenhouse.

Another element of gender empowerment was the participation of female trainers in the training of trainers program. A total of 7 female trainers and 52 female farmers completed the training course offered by GEBAL's trainers as part of this project. A particular success of the training of trainers was the training of 3 female trainers from Baharyia Oasis and 4 female trainers from Dandara and Esna.

The female trainers from Bahariya trained local male farmers on nexus farming, which was an absolute first in the oasis, which is marked by a conservative culture of gender segregation.

GEBAL's nexus greenhouse thus offers considerable opportunities for women's entrepreneurship in farming. However, discussions with representatives of financing institutions have also shown that it is much harder for women to access funding in the form of agricultural loans. Most loans require the submission of papers on land ownership that women simply do not have. At present, less than 5% of agricultural land in Egypt is owned by women. Therefore, enabling women's access to loans and funding in the context of sustainable agricultural entrepreneurship remains a matter of necessity.

Solar-powered solutions for operating nexus greenhouses are not only cheaper to operate, but are also easier to maintain and have a longer life span. Especially in the context of solar panels, the life span is calculated at a duration of at least 25 years. Solar pumping requires a lot less manual labor and can easily be handled by women and young people. Solar-powered irrigation thus opens significant opportunities for transformation of the gender division of labor in the agricultural sector, as well as the engagement of youth in agriculture.

GEBAL not only actively involved women in the project's training activities, but also in the design of solutions. The Design Thinking workshops that were carried out in Dandara and El Heiz in engaged women as well as men. While only four women participated in El Heiz, where the culture is much more conservative than in Upper Egypt, more women than men participated in the Design Thinking workshop in Dandara (Table 7). It was absolutely critical to include women's perspectives in the design of nexus solutions in order to ensure that the interests of both women and men were reflected in the proposed solutions.

Table 7: Engagement of Women in Creative Thinking and the Design of Solutions

Location	Male Participants	Female Participants
El Heiz	14	4
Dandara	11	12
Both Locations	25	14

SDG 6: Clean Water and Sanitation

1. Water Saving through Nexus Farming

Besides the access to clean water and sanitation, efficient water use and water management are an important component of SDG 6. In Egypt, agricultural consumes over 80% of freshwater, meaning that transforming water use in agriculture is a central aspect of sustainable development in Egypt. The design of GEBAL's nexus greenhouse has considerable potential to reduce the need for irrigation water per unit of food produced, while also ensuring "more crop per drop". The greenhouse design enables the production of both fish and crops with a similar amount of water, as well as a reuse of water in the agricultural system.

The data collection in the greenhouses throughout the growing season was concerned with the question of how much water the nexus greenhouses really need, and to compare this water consumption with conventional growing methods. For this reason, the greenhouses were equipped with water meters that measured water that was entered the system (from the well or Nile) to top up the fishpond (irrigation water is always taken out of the fishpond), and water that left the pond for irrigation purposes. The local researchers read these meters every day throughout the research period. In this way, it was possible to measure the water consumption per day. Table 8 provides an overview of the water consumption in the two systems:

Table 8: Water consumption for irrigatoin in the greenhouses in Dandara and El Heiz (data collection in El Heiz between August 2022 and June 2023, and in Dandara between November 2022 and June 2023)

Location	Average Total Daily Water Use (m3)	Total Irrigation Water (m3)	Average Daily Irrigation Water Use (m3)
El Heiz	1.84	369	1.51
Dandara	3.8	158.8	0.8

The greenhouse in El Heiz used a daily average of 1.84 m3 of water, out of which 1.51 m3 of water was used for irrigation and the remainder to operate the fishpond. In Dandara, an average of 0.69 m3 of water was used per day, out of which 0.57 m3 was used for irrigation. This number is interesting, given that the greenhouse in Dandara is much larger than the greenhouse in El Heiz. However, due to the cooling function, in the greenhouse in Dandara an irrigation time of 10-15 mins per day is sufficient. In El Heiz, plants are irrigated for 30 mins per day. This means that the much larger greenhouse can be operated with around ⅓ of the irrigation water needed in El Heiz. However, given that the cooling system in the greenhouse is based on water-based evaporative cooling, the cooling system itself needs around 3 m3 of water per day. Including the water needed to operate the fishpond, the total water use of the greenhouse in Dandara adds up to 4 m3 per day. This number, however, is dependent on the season. During the winter months, the cooling system does not need to operate as frequently as during the summer months, bringing down the total water consumption. The greenhouse in Dandara is 2.6 times as large as the greenhouse in El Heiz and uses around 2.6 times as much water. This means that the cooling system itself does not necessarily contribute to water savings, at least not in the warmer months when the cooling system operates a lot. However, the cooler conditions in the greenhouse contribute significantly to the quality of the produce.

The water consumption of the nexus greenhouse needs to be compared with the water consumption of conventional agriculture in the two locations. Growing peppers on an open field the same size of the greenhouse in El Heiz will consume a calculated average of 3.92 m3 of water per day (well capacity 80 m3 / hour * 6 hours, calculated on a weekly basis - 1 day per week, 27.4 m3 / 7). In Dandara, a comparative piece of land with the same size of the greenhouse will use a calculated average of 9.47 m3 of water per day.

This means that, in the case of El Heiz, the nexus greenhouse saves an estimated 2.4 m3 or **37.5%** of water per day, while in Dandara it saves 5.47 m3 of water per day or **42.2%** of water. Across an entire year, the greenhouse in El Heiz saves **876 m3** of water, the one in Dandara **1,996 m3** as compared to conventional flood irrigation practiced on pieces of land of the same sizes as the greenhouses.

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SDG 7: Clean and Affordable Energy

1. Diesel Consumption in Egyptian Agriculture

Farming in Egypt is almost inextricably linked to pumping. While water for farming is not metered and therefore not priced, there are indirect expenses for irrigation through the cost of pumping. In the Delta, farmers are operating small Diesel pumps that they drag to the canals where they are needed to pump water from the canal level up to the field level. In reclaimed desert land near the Delta or Nile Valley, large irrigation pumps are often powered by grid electricity. In remote areas, large Diesel pumps are traditionally used to pump water out of aquifers and then into agricultural canals, where they are transported to the fields by gravity only. The use of Diesel and electricity in pumping is becoming increasingly expensive, due to price increases that are based on the roll-back of state subsidies as well as market price fluctuation and inflation. Many farmers are finding it harder and harder to irrigate all of their land using Diesel fuel.

For this reason, solar pumping is becoming more and more popular in Egypt. Although solar cells and pump drives are not yet produced in Egypt, their prices have come down significantly over the past decade due to imports from China (the fluctuating dollar exchange rate in Egypt is now making these products more expensive again). Pumps on newly reclaimed lands in Egypt are usually solar pumps, and even small farmers make this comparatively large initial investment in order to save on operational expenses later. It is often groups of small farmers who pool money and buy a solar pump and pump drive together and then share the water.

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2. Saving on Fossil Fuels through Nexus Farming

GEBAL's nexus greenhouse models are entirely powered by solar energy. This makes a lot of sense in Egypt, given the many sunny days and the long sunshine hours. During the trials at the greenhouse sites in El Heiz and Dandara, the operators were reading electricity meters in order to determine the daily electricity consumption of the models:

Table 9: Energy consumption of nexus greenhouses at the two sites throughout the data collection time (data collection in El Heiz between August 2022 and June 2023, and in Dandara between November 2022 and June 2023)

Location	Total Energy for Irrigation and Fishpond in kWh	Average Daily Energy Consumption in kWh	Total Energy Consumption for Cooling in kWh	Average Daily Energy Consumption for Cooling in kWh
El Heiz	351.8	1.52	N/A	N/A
Dandara	373.6	1.8	2,952.1	14.2

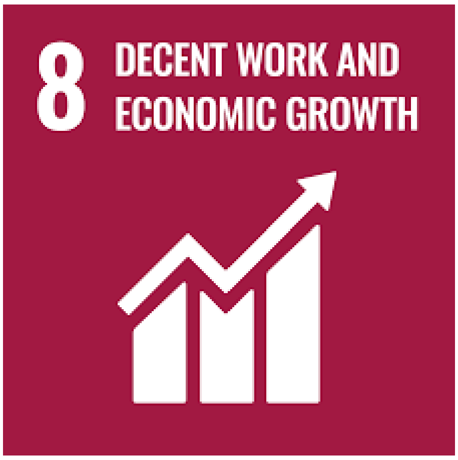
If the energy consumption for irrigation is related to the square meters (m^2) of agricultural production area – 240 in El Heiz and 640 in Dandara – it become clear that, energy-wise, the system in Dandara is more energy-efficient. However, the cooling system in Dandara is also comparatively energy intensive. Given that it is entirely produced by solar energy still ensures its sustainability.

Operating the irrigation and aeration pump for the fishpond in El Heiz (0.6 HP operating for 12 hours per day, 7.2 HP per day) would require Diesel consumption of 657 Liters per year. Operating the greenhouse in Dandara (7.5 HP per hour, 7-8 hours per day, plus an irrigation and aeration system of 0.6 HP as above in El Heiz) for a year with a Diesel generator and pump each day would require a yearly Diesel consumption of 5,447.6 Liters.

The systems thus save **657 Liters** of Diesel per year in El Heiz and **5,447.6 Liters** in Dandara. At the current Diesel price of 8 EGP per Liter, this would translate into an annual savings of **5,256 EGP** for a farmer in El Heiz and of **43,580 EGP** per year in Dandara.

Solar-powered solutions for operating nexus greenhouses are not only cheaper to operate, but are also easier to maintain and have a longer life span. Especially in the context of solar panels, the life span is calculated at a duration of at least 25 years. Solar pumping requires a lot less manual labor and can easily be handled by women and young people. Solar-powered irrigation thus opens significant opportunities for transformation of the gender division of labor in the agricultural sector, as well as the engagement of youth in agriculture. However, the operation of maintenance of a solar system also requires some training in order to be sustainable. This is why GEBAL routinely trains the operators of its nexus greenhouses. Moreover, the operation and maintenance of solar systems was included in the training of trainers that was delivered as part of this project.

SDG 8: Decent Work and Economic Growth



Farmers in Egypt's rural areas often do not get as much money for their products as they deserve. This is the case because products are often sold at farmgate - at which traders play a significant part in determining the price - or on lower price rural markets. The nexus greenhouse gives farmers the opportunity to produce a higher quality product that can be marketed at a higher price. The fact that the crops are produced with a minimal input of chemical fertilizer and makes use of the natural fertilizer found in the fishpond increases the value of the product. In order to receive a higher price, however, farmers have to target higher range markets, which requires a careful market analysis. Marketing the product at a higher price is also easier in some locations (such as Dandara, where there are hotels and hypermarkets nearby) than others (for example El Heiz, which is geographically quite removed from high end markets). This would mean that the nexus greenhouses would create better working conditions with higher income opportunities for local farmers.

The peppers produced in the greenhouse in El Heiz were sold at prices between a kg price of 4 EGP (to a shop in nearby Bahariya oasis) and 7.5 EGP (residents of El Heiz oasis who would pick up the peppers or receive them through delivery). In Dandara, the peppers were sold at an average kg price of 8 EGP. In both cases, an increase in the price might be possible through clever marketing and presentation, which would raise the value of the product on the market. However, obtaining prices such as the ones assumed in the feasibility study based on Cairo require access to higher-end markets. To ensure a sustainable growth of the system operations based on the GEBAL models, there are also opportunities to grow higher-end products in the greenhouse such as medicinal plants and "boutique" vegetables that can be sold at higher prices. Again, however, the market depends on the location of the greenhouse. As stated above, the greenhouse model also offers interesting working opportunities for groups of women. The working and income opportunities, the access to better markets, the engagement of women in the production process, and the training opportunities that farmers had access to through this project are all connected to **SDG 10** as well, **Reduced Inequalities**.

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SDGs 11 and 12: Sustainable Cities and Communities / Responsible Consumption and Production

Construction, transportation, farming, packaging, and consumption are all processes that are not always very sustainable in Egypt. As mentioned before the use of Diesel-powered pumps and vehicles, old pumps and vehicles that are responsible for increased air pollution, unsustainable farming techniques that are not very water- or energy-efficient and that depend on chemical fertilizer and pesticides, packaging of food and agricultural products in plastic and Styrofoam materials, and the consumption of unhealthy food are all examples of unsustainable living patterns in Egypt's communities. Daily behaviors, including the farming process, are often high in CO2 emissions and contribute negatively to the country's carbon footprint.

GEBAL's nexus greenhouses are models and living labs built close to farming communities that function as examples of how farming and food production can possibly be more sustainable. Showing farmers a model of efficient water and electricity consumption that has zero carbon emissions and that increases food production while lowering resource consumption is an important step towards upscaling such sustainable practices. The greenhouses are thus examples of production models that are more responsible in regard to their ecological footprint and impact on environment and ecosystems. Moreover, they are examples that can trigger more responsible consumption patterns that are based on sustainable production methods. Having more of such nexus farming greenhouses can help build a consumer group that is aware of and appreciates the health benefits of farming with as little chemicals as possible.

Farmers in Egypt need to see working models in front of them, see these practices with their own eyes, ask questions, and talk to the operators in order to become convinced of the many benefits such sustainable farming approaches offer. GEBAL has shown with this project that the models are not only more sustainable for environment, planet, and people, but can also be lucrative businesses that can raise farmers' incomes.

In order to scale up the use and boost the uptake of such sustainable farming models requires the creation of an enabling policy and financing environment that helps farmers replicate these models on their own. The workshops for policymakers GEBAL carried out as part of his project resulted in the idea that such sustainable model nexus farms should be implemented in every rural community in Egypt, possibly as part of, or in connection with, existing national policy programs that are targeted at enhancing the living conditions in Egypt's rural areas (such as Haya Karima). In this way, farmers would not only be directly exposed to such sustainable models, but the models could also function as training and capacity development centers for more sustainable farming practices that would ultimately contribute towards building more sustainable communities in Egypt.

SDG 13: Climate Action

1. Cutting back on CO2 emissions through nexus farming

Given the reliance of the Egyptian farming system on Diesel consumption for pumping and irrigation, the agricultural sector produces CO2 emissions each year. In comparison to the water footprint of Egyptian agriculture (over 80% of freshwater is used in agriculture), the sector emitted only around 2.4% of CO2 emissions in 2019/20 according to Statista. Nevertheless, turning to nexus farming holds significant potential for scaling back carbon emissions caused by agricultural production. For our trials carried out in El Heiz and Dandara, we have calculated the emissions savings for the operation of greenhouses and irrigation only. Further savings are possible through reductions in the need for food transportation and the production of chemical fertilizer. In a cradle to grave assessment, a full carbon footprint calculation would also have to take into account the carbon emissions caused by the production of the greenhouse infrastructure, panels, and technical equipment. Table 10 shows a simplified calculation of carbon emission reductions based on the operation of a solar system versus a Diesel pump.

Table 10: Carbon emission savings from PV operation of the greenhouse models

Location	Annual CO2 emission savings as compared to Diesel-powered generator (based on 2.5kg CO2/l) (in kg)
El Heiz	1,642.5
Dandara	13,619

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