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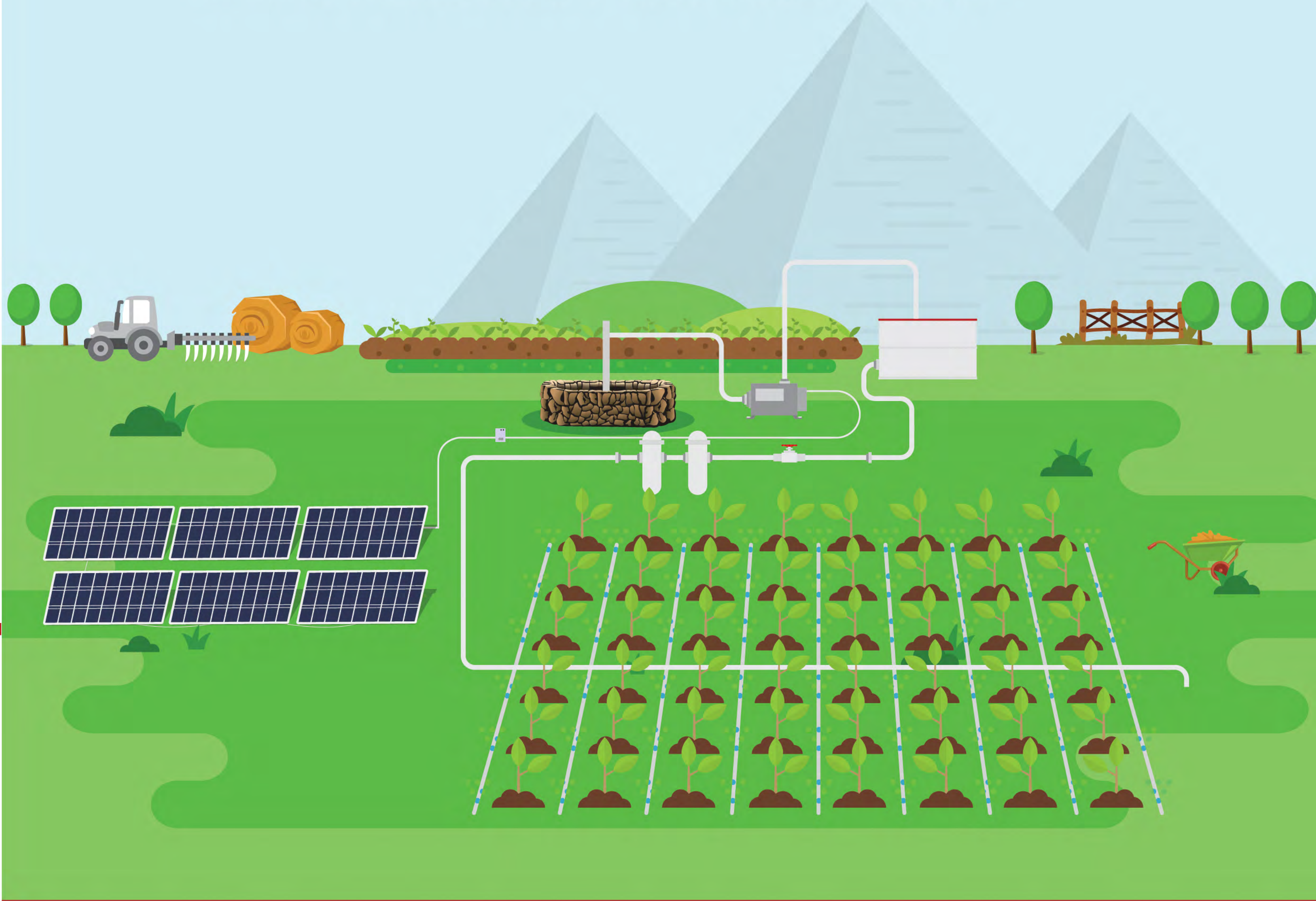
Regional Center for Renewable Energy and Energy Efficiency
المركز الإقليمي للطاقة المتجددة وكفاءة الطاقة

# Market Assessment Study of

## Socio-Economic Impacts of Solar Pumping Systems
in Terms of Local Job and Value Creation in Egypt.



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## About RCREEE

The Regional Centre for Renewable Energy and Energy Efficiency (RCREEE) is an independent intergovernmental regional organization which mission is to facilitate, increase and mainstream the adoption of renewable energy and energy efficiency practices in the Arab region. RCREEE teams up with regional governments and global organizations to initiate and lead clean energy policy dialogues, strategies, technologies and capacity development in order to increase Arab states' share of tomorrow's energy.
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## About RE-ACTIVATE

RE-ACTIVATE is a regional project for "Promoting Employment through Renewable Energy and Energy Efficiency (RE/EE) in the Middle East and North Africa (MENA) (RE-ACTIVATE)", funded by the Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by GIZ in cooperation with RCREEE to support the national (Egypt) and regional cross-border cooperation and knowhow transfer on employment promotion through RE/EE in the MENA region.

## Disclaimer



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# Abbreviations

| | |
|---|---|
| **ABE** | Agriculture Bank of Egypt |
| **AFD** | Agence Française de Développement (The French Development Agency) |
| **AfDB** | African Development Bank |
| **AC** | Alternating Current |
| **AOI** | Arab Organization for Industrialization |
| **ARECO** | Arab Renewable Energy Company |
| **ARL** | Agrarian Reform Laws |
| **BCM** | Billion Cubic Meters |
| **CAPMAS** | Central Agency for Mobilization and Statistics |
| **CBE** | Central Bank of Egypt |
| **CDC** | Cairo Demographic Center |
| **cm** | Centimetre |
| **DAT** | Dual Axis Tracker |
| **DC** | Direct Current |
| **EBRD** | European Bank of Reconstruction and Development |
| **EFSA** | Egyptian Financial Supervisory Authority |
| **EGP** | Egyptian Pound |
| **ESCos** | Energy Service Companies |
| **EU** | European Union |
| **FA** | Farmer's Association |
| **FAO** | Food and Agriculture Organization |
| **FiT** | Feed-In Tariff |
| **FU** | Farmers' Union |
| **GDP** | Gross Domestic Product |
| **GEFF** | Green Economy Financing Facility |

| | |
|---|---|
| **GoE** | Government of Egypt |
| **HAD** | High Aswan Dam |
| **hr** | Hour |
| **hp** | Horse Power |
| **HSAT** | Horizontal Single Axis Tracker |
| **IRENA** | International Renewable Energy Agency |
| **IRR** | Internal Rate of Return |
| **ISAT** | Inclined Single Axis Tracker |
| **kg** | Kilogram |
| **km** | Kilometre |
| **kW** | Kilo Watt |
| **kWp** | Kilo Watt peak |
| **LCoE** | Levelized Cost of Electricity |
| **l** | Litre |
| **m** | Meters |
| **$m^3$** | Cubic meter |
| **mm** | Millimetre |
| **MoALR** | Ministry of Agriculture and Land Reclamation |
| **MoPMR** | Ministry of Petroleum and Mineral Resources |
| **MoERE** | Ministry of Electricity and Renewable Energy |
| **MoTI** | Ministry of Trade and Industry |
| **MoWRI** | Ministry of Water Resources and Irrigation |
| **MSME** | Micro, Small and Medium Enterprises |
| **MSM-EDA** | Micro, Small and Medium Enterprise Development Agency |
| **MW** | Mega Watt |

| | |
|---|---|
| **NBK** | National Bank of Kuwait |
| **NOMP** | National Organization for Military Production |
| **NPV** | Net Present Value |
| **NREA** | New and Renewable Energy Authority |
| **OBG** | Oxford Business Group |
| **OH** | Owned Holding |
| **O&M** | Operation and Maintenance |
| **PBP** | Payback Period |
| **PV** | Photovoltaic |
| **PVC** | Polyvinyl Chloride |
| **PVP** | Photovoltaic Pumping |
| **QNB** | Qatar National Bank |
| **RE** | Renewable Energy |
| **RH** | Rental Holding |
| **SME** | Small and Medium Enterprise |
| **SPIS** | Solar Pumping Irrigation System |
| **SWH** | Solar Water Heater |
| **SWP** | Solar Water Pumping / Pump |
| **USD** | United States' Dollar |
| **WEF** | Water Energy Food |


Executive

# Executive Summary

# Executive Summary

Since ancient times, the agriculture sector has been a cornerstone in Egyptian economy. Until now, agriculture is one of the important sectors for its contribution to the national GDP (11.9% in 2016) and for being one of most labour intensive sectors, employing around 30% of the labour force. Furthermore, the agriculture activities contribute to the food security and require stable and reliable water and energy supply for its smooth operations, including increasing productivity and efficient outcomes.

With the announcements of the Sustainable Development Goals, the nexus for water, energy and food has been attracting increasing attention, also for its socio-economic impacts through contributing to poverty reduction, increasing agriculture productivity and more efficient use of water and energy, which eventually contributes to water, energy and food security.

The purpose of this study is to assess the potential market for using solar pumping systems in the agriculture sector and its socio-economic impacts in terms of creating jobs and local value in Egypt. The report started with displaying the current status quo of the agriculture and irrigation sectors, with reference to the common practices in both sectors.

Egypt is endowed with four main agro-ecological zones; (1) the northern coastal belts, (2) the Nile valley, (3) the inland Sinai and Eastern desert, and (4) the western desert. Each zone has specific attributes of resources base, climatic features, terrain and geographic characteristics, land use patterns and socio-economic implications. The total agriculture area accounts for 9.08 million feddans along the whole country (MoALR, 2010) and the total possessions reported for this area is 4.42 million landholdings, where the simple average of two feddans per possession reflects the high degree of fragmentations (especially for the possessions of less than five feddans). The landholdings take one of three common forms: (1) land ownership, (2) mixed landholding, and (3) land rental (either cash- or crop-sharing). The agricultural land located in the Nile Valley and delta is mostly referred to as "old land", whereas the agriculture area after 1970 located at the fringe of Nile Valley and delta, and also in other locations in the deserts and oases, is mostly referred to as "new land". Since 2014, a new national project was announced and is being implemented in phases to increase the agriculture area (hence horizontal expansion) by around three million feddans in selected locations in the deserts, using underground water for irrigation and ideally relying on renewable energy solutions to serve the remote areas (where applicable). In parallel, there are different initiatives to support the vertical expansion through using modern and suitable farming technologies to enhance crops intensification using high yielding varieties.

In general, the Egyptian irrigation system is considered a "closed system" that has the Nile River as the main inlet and other minors resources represented in the rainfall (especially in the coastal zone during the winter) and the underground water in the deserts. A complete network of canals and drains are extended from the south at Aswan to the Mediterranean Sea, mainly through gravity system. The cultivated areas in the Nile Valley and Delta are irrigated using surface water and are therefore served by around 31,000 km of public canals, where the main (principal) canals extend over 1,000 km and the distributary or branch canals extend over 30,000 km, while the minor canals (also referred to as Mesqas) extend over 80,000 km to deliver water either directly to the fields or through smaller outlets (also referred to as Marwas); and the drainage canals extend over 17,000 km. This irrigation system secures the irrigation necessary for cultivation and other agricultural activities the whole year round. The flow of water is regulated barrages, head regulators and intermediate regulators along the Nile River, main and branch canals respectively, as well as 670 large pumping stations along the Nile River, which are all operated by the Ministry of Water Resources and Irrigation (MoWRI). Since there is no dictated cropping pattern in Egypt since 1990 and the

farmers are free to grow crops based on individual preference, the MoWRI is facing an additional challenge in regulating the water flow necessary to meet the requirements of the cultivated crops, since different crops have different requirements for water and different water unit productivity. This issue requires closer coordination between the key stakeholders, the Ministry of Agriculture and Land Reclamation (MoALR) being in charge of the cultivation and crop pattern and the MoWRI, being in charge of the irrigation activities.

Egypt's water share in the Nile River is fixed to 55.5 billion $m^3$ per year, based on the Nile water agreement with the Nile Basin Countries, which represents 66% of its overall water resources. Compared to other neighbour countries, Egypt has the highest dependency ratio of 96.9%. The agriculture sector is the largest water-consuming sector, withdrawing around 70% of the total water resources. Therefore, sustainable and efficient use of underground water is on the top of the government's priority for the successful implementations related to the foreseen horizontal expansion. Accordingly, drip and sprinkler irrigation are the commonly used methods for irrigation activities in the new lands, compared to the flood irrigation method which is the common practice in the old lands using surface water for irrigation.

There are eight main aquifers in Egypt: (1) the Nile Valley and delta aquifers, (2) the coastal aquifer, (3) Nubian sandstone aquifer, (4) Moghra aquifer, (5) Tertiary aquifer, (6) Carbonate aquifer, (7) Fissured basement complex aquifer, and (8) Aquiclude aquifer. Each of these aquifers has different hydrological characteristics, with different quality of soil, water and depths of underground water.

The statistics and recent data investigated in this report showed that diesel pumps are being the common practice used for irrigating fields. Accordingly, this introduces another two key stakeholders in the government for the solar pumping applications, these are the Ministry of Petroleum and Natural Resources (MoPNR) and the Ministry of Electricity and Renewable Energy (MoERE). In total, there are 957,534 water pumps used for irrigation purposes and with different capacities, depending on the depth of water (hence pump head) and irrigated area (hence number of feddans). In general, the main governorates with highest numbers of irrigation machines are: (1) Behera, (2) Sharkia, (3) Gharbia, (4) Kafr Elsheikh and (7) Menofia in Lower Egypt, and (5) Beni Suef, and (6) Menia in Middle Egypt (numbered in descending order). The available pumps were classified to (1) mobility: fixed (~82%) and portable (~18%) pumps; (2) water source: deep wells (~15%) and surface water (~85%). The different capacities under each classification were investigated: (1) capacities for fixed water pumps: <15 hp, between 16 and 25 hp, between 25 and 45 hp, and more than 45 hp; (2) capacities for portable water pumps: <5 hp, between 6 and 9 hp, between 10 and 12 hp, and more than 12 hp. It was deduced from this analysis that solar pumping solutions could be applied for both, surface water and underground water irrigation, especially when high value crops were cultivated to secure higher cash flows for the farmers and therefore shorter payback period.

Based on this background, more in-depth information was given for the different types of available solar pumping solutions: (1) surface mounted pumps, and (2) submersible pumps. In addition, the main components for the solar pumping solutions were illustrated and for the common technical designs in the local market. Since financial institutions usually have an important role in scaling up the markets, the available financial mechanisms and incentives from different institutions were highlighted, both from the governmental perspective (MoALR and MoWRI) and also from the perspective of different financial institutions (financial loans, subsidized loans and leasing options), as well as from the perspective of international initiatives (as Green Funding Facilities).

There are many success stories for the implementation of solar pumping solutions in different locations along the country, both on the public sector (as MoWRI) and on the private sector (communities in the Western dessert), mainly using underground water for irrigation (as in Moghra and Toshka). These examples indicated that there is already an existing market for solar pumping solutions, especially for remote areas. Therefore, the national project to cultivate addition three million feddans based on underground water introduces a reasonable market potential for the deployment of the solar pumping solutions.

A very conservative model was used to calculate the market potential for solar pumping solutions in Egypt, also based on the analysis of available data and market insights regarding the current status of implementations. The market potential was investigated from different perspectives:

1. Potential based on expected efficiency and lifetime of existing pumps: 39% and 42% of irrigation machines and water pumps (i.e. 369,937 and 400,460) respectively are being using for more than 27 years (purchased before 1994). A well designed replacement program supported by reasonable incentives from the government could serve in creating more stable market for solar pumping in the coming few years, resulting in substantial savings in fuel consumptions.
2. Potential based on mobility of existing pumps: more than 18% of existing pumps are fixed (175,016 pumps); therefore, the solar PV panels could be installed on the roof of their protecting structures. On the other hand, around 75% of the portable pumps (i.e. 589,078) are of capacities less than 9 hp.
3. Potential based on applied capacities: more than 75% of the portable pumps are less than 10 hp in capacity (i.e. 392,639 pumps); where innovative solutions could also be adopted for solar pumping also using surface irrigation (especially in Lower Egypt, where more than 50% of the portable pumps are located).
4. Potential based on landholdings and possessions: around 80% of the reported possessions (i.e. 1,305,674 possessions) are using pumps of capacity less than 16 hp. This marks a significant potential for innovative solutions for solar pumping, suitable for the highly fragmented possession.
5. Potential based on new national project: at least 150,000 solar pumping solutions could be installed for cultivating the new areas (each of capacity 20 kWp). A more realistic potential is rather 300,000 SWP solutions, since one SWP could serve an area of five feddans on average rather than ten.

In applying the same conservative model to estimate the impact on the local value chain and job creation, a bottom-up approach was followed, based on real cases for implementations. A total of 5,000 water pumps were expected to be converted diesel pumps to solar pumping system, with each system of capacity of 20 kWp. Accordingly, the potential of 100 MW of installations per year for solar pumping solutions was considered.

For simplicity and to avoid confusions, jobs' creation was referred to as a total number for both, the direct and indirect jobs especially that the conformity in defining both terms was missing in available literature and would cause unnecessary debate. Since most of the solar pumping systems are imported, the jobs created during the manufacturing phase were not considered, as well as induced jobs were not calculated for the same reason mentioned earlier. Furthermore, the jobs considered in the calculations were mainly related to the local market, mainly for installations, operation and maintenance, electric connections, connecting pipes and fittings, civil works and construction, transportation and handling, as well as site preparation and carriers. The outcome of this conservative model showed that at least 4.59 jobs could be created for every 1 MW installations per year, and for an average annual investment of ~USD 113 million (~EGP 2 billion).

Comparing this outcome to available literature for the region showing an employment factor for the solar PV technology ranging between 3.9 and 23.6 per MW installed proved to be though conservative, yet reasonable and hence achievable. In addition to the positive contribution to the socio-economic impacts of solar pumping solutions, it contributes also to the announced targets aiming at increasing the share of renewable energy solutions by 2022 and 2035.

In all cases, this study proved that there is an existing market and considerable potential market for solar pumping solutions in Egypt. To boost this market, the laws and policies governing the efficient use of water, underground water sustainability, food and energy security need to be revisited and enforced to achieve the best possible results. Besides, tailor-made financial mechanisms and different incentive schemes need to be introduced, promoted and implemented, especially to motivate the micro and small farmers to make this decision. In this regard, further investigations and more detailed studies are encouraged.

# Introduction

# 1 Introduction

For decades, Egypt was well-known for its agricultural activities, that it produced enough food to meet most of the domestic demand and was an important food exporter to different countries across the MENA regions. However, the situation has changed since the 1980s and nowadays Egypt is importing more than 50% of its supply of wide range of food products to meet domestic demand and is considered the largest importer for wheat according to the Food and Agriculture Organisation (FAO). This major shift was due to a range of factors, including rapid population growth - expected to reach 110 million by 2031 and 128 million by 2051 as per the Cairo Demographic Center (CDC); a shortage of arable land and agricultural water resources; increase in urbanization that contributed to a shrinking domestic agricultural workforce; lack of public and private investments in modern agricultural technology and new practices; and recent economic and political instabilities, which have had a major impact on Egypt's agricultural sector (OBG, 2017)

Despite these factors, the agriculture sector remains a cornerstone of and one of the largest contributors to Egypt's economy, in terms of both overall value-added and employment. According to the World Bank, the agriculture sector accounted for 11.9% of Egypt's GDP (Worldbank, 2016) and employed almost 26% of the workforce (Worldbank, 2015). Besides, energy is an important component of agriculture production and hence contributes not only to energy security, but also to food security. Among the most effective ways to fight poverty and stimulate the socio-economic development is to increase agriculture productivity (IRENA, 2016).

However, Egypt's agriculture sector still faces a wide range of challenges regarding the development of the sector in the coming years. For instance, the booming population growth has contributed to an increase in agricultural consumption in recent years. The continuously increasing rates of inflation are also an issue, with the annual food and beverage inflation rate at 13.8% as of October 2016 compared to 11% the year before (OBG, 2017). Given that the Egyptian pound was further devalued in November 2016, as of early 2017 the inflation rate was expected to have an impact also on the imported agro-food products as well as on renewable energy (RE) equipment and systems. Other ongoing hurdles to growth include the low availability and high cost of arable land, almost all of which lies along the Nile and across the Nile Delta, which is Egypt's sole source of moving freshwater; issues related to irrigation, which is an ongoing problem in Egypt's arid climate; and agricultural infrastructure, which remains underdeveloped by international standards.

Starting 2014, the government of Egypt (GoE) has set out a series of ambitious agriculture-focused programmes. Many of these initiatives were designed to address the various challenges named above. Indeed, the state's efforts to irrigate regions of the desert, to make it useful as farmland, have the potential to expand the nation's total supply of arable land by one-sixth by the end of 2018 (OBG, 2017). The government's investments in the agricultural sector are growing and will also require parallel increase in the credit facilities and innovative financial mechanisms to boost the sustainable development in the agriculture sector, which will inevitably entail sustainability of water and energy resources as well as food, with consideration to the fast population growth that imposes more challenges with respect to water, energy and food. Accordingly, the application of integrated, cross functional and cross ministerial approaches is encouraged to achieve synergies, through collaboration between the private and public sectors.

Furthermore, the Water, Energy and Food (WEF) nexus is gaining momentum and becoming more regional and international topic rather than national, and therefore attracting more attention from the national and regional governments, as well as international donors and investors.

Egypt produces a wide range of crops and other agricultural products, including cereals (wheat, corn rice), fruits and vegetables, sugar, cotton, dairy products, livestock and fish, among others. Solid support for agricultural activity on the part of the government and new opportunities for domestic and foreign investors alike point to expansion of the sector in the coming years (OBG, 2017).

With small-scale farming accounting for around 90% of the country's active farmers, according to the UN Food and Agriculture Organisation (FAO), and industrial-scale farming comprising just 5-7% of production, some within the sector have urged the creation of cooperatives to assist in marketing products and to encourage and support technological improvements (OBG, 2016).

Hence, building on the fact that Egypt is rich with regard to its solar energy potential and solar photovoltaic (PV) technology is increasingly perceived as a cost effective alternative energy source, it could be used to meet the growing energy demand in off-grid areas across the agriculture sector. Furthermore, the applications of decentralized solar water pumping solutions in the agro-food sector have a strong potential for creating jobs, especially in the small and medium enterprises.

The Solar Water Pumping (SWP) system is a complete irrigation system powered by solar energy (from the sun), which provides fresh water from a well (underground water), or from a reservoir (water storage unit) or from canals (surface water) to be used for irrigation and agriculture purposes. In Egypt, water pumps used for irrigation are powered by either diesel (mostly) or electricity. The SWP systems are designed to harness the energy radiated from the sun through solar panels in order to drive the water pumps to be used for irrigation purposes. In literature, the SWP systems are sometimes referred to as Solar Pumping Irrigation Systems (SPIS) or as Photovoltaic Pumping (PVP).

The objective of this study is to gain an understanding of the market, including the geographical areas with highest demand and potential for SWP solutions, the irrigations practices currently used, the available suppliers and existing financing mechanisms, and to identify the barriers to upscale the SWP market in Egypt.

# Status Quo of Agriculture and Irrigation Practices in Egypt

# 2 Status Quo of Agriculture and Irrigation Practices in Egypt

To assess the socio-economic impact of solar water pumping solutions, we need first to understand the main characteristics of the agriculture and irrigation sectors, to find out where the potential is and how this potential could be translated in terms of creating local value and jobs opportunities.

## 2.1 Agriculture Sector and Common Practices

The agricultural sector plays a central role in the Egyptian economy, contributing by 11.9% to GDP; and it is the largest labour-intensive sector as it accounts for more than 26% of the work force (Worldbank, 2016). Egyptian policymakers pay special attention on the agricultural sector for its importance in ensuring food security to the rapidly growing population. Throughout the past five decades, the Egyptian agricultural sector was subject to major policy changes that had substantial impact on this sector; hence greatly caused major shifts in the cropping pattern and accordingly had applied the policy of horizontal expansion through reclaiming new lands to increase the agriculture and cultivated area.

The main agriculture activities lie under the responsibility of the Ministry of Agriculture and Land Reclamation (MoALR). However, since agriculture relies on water, there is intensive and continuous cooperation and collaboration with the Ministry of Water Resources and Irrigation (MoWRI).

### 2.1.1 Agro-Ecological Zones

Egypt has total area of about one million square kilometers , under arid and hyper arid climatic conditions, of which only a small portion (around 3% of total area) is agriculturally productive. The country is endowed with four main agro-ecological zones, as illustrated in Figure 2.1. Each zone has specific attributes of resources base, climatic features, terrain and geographic characteristics, land use patterns and socio-economic implications.

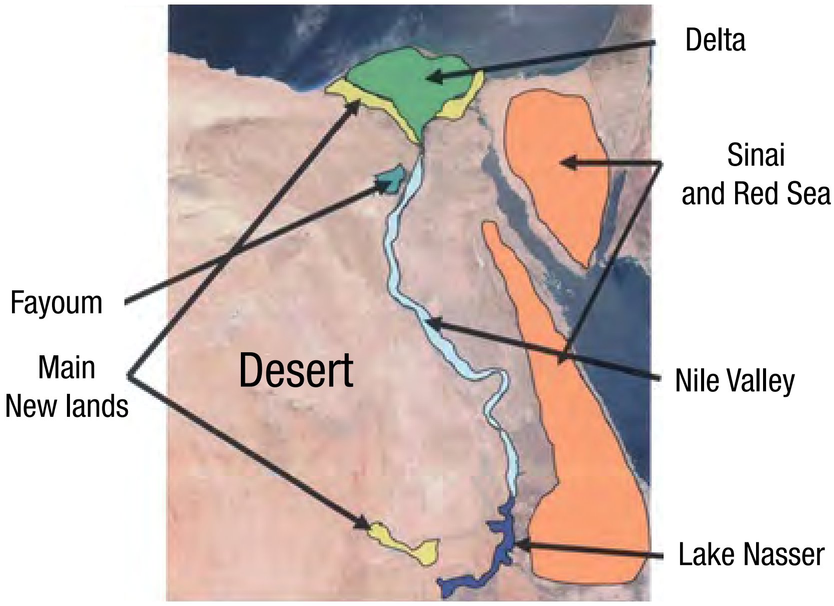


**Figure 2.1:** Agro-Ecological Zones in Egypt (El-Kassar, 2008)

These zones are identified as follows:

1. **Northern Coastal Belts** including:

   a. **North West Coastal Areas:** extending for about 500 km between Alexandria and El-Salloum. Water resources are mainly that of rainfall (~105 – 199.6 mm/year), where 70% of rainfall is between November and February.

   b. **North Coastal Areas of Sinai:** The eastern parts of the coastal areas have the highest average rainfall in Egypt (~304 mm/year in Rafah), where 60% of rainfall is between November and March. However, rainfall runoffs occur only if the rainfall exceeds 10 mm per rainy storm. It is estimated that 60 % of the mean rainfall in Sinai is lost to evapotranspiration.

   "Al-Salam Canal" is being introduced to this area, to convey mixed Nile and agricultural drainage water across the Suez Canal to reclaim 400,000 feddans[1] in North Sinai.

   The underground water resources are limited in this zone and are usually of low quality due to varied salinity content. Besides, saline soil is found exclusively in this zone.

2. **The Nile Valley:**

   encompassing the fertile alluvial lands of Upper Egypt and the Delta (most fertile lands) and the reclaimed desert areas in the fringes of the Nile Valley. This zone represents most of cultivated lands of the Nile Valley, as well as most of the reclaimed desert lands, mainly, on the western and eastern fringes of the Delta in addition to relatively limited areas on fringes of the Valley in Upper Egypt (total area over 7.5 million feddans).

   The Nile River is the main water resource for this zone, while the underground water (mostly recharged by the Nile water) is of relatively limited use in the Nile valley but is specially used in the desert fringes.

[1] In Egypt, the unit used for measuring the agriculture area is called "feddan", which is equivalent to 4,200 $m^2$. Each feddan is divided into 24 kerat, each is equivalent to 175 $m^2$. In case comparison is needed with other units, 1 feddan is equivalent to 0.42 hectares and 1.038 acres.

3. **The Inland Sinai and the Eastern Desert with its elevated southern areas:**
   There are mostly high Rocky Mountains and desert floor covered with polished pebbles. On the plain areas located to the east of Suez Canal, in El-Gifgafa and El-Qaa have agriculture utilization potential. Rainfalls in this zone despite being low tend to be intense with flash floods causing adverse impact especially on soil erosion.

4. **The Western Desert, Oases and Southern Remote Areas:** including East Owenat Tock and Drab El Arabian Areas and Oases of the Western Desert:
   This zone is famous of different oases, like Siwa in the north, Baharia and Frafra in the central section, which are distinguished with artesian wells with high discharge of fresh water. In addition, the huge Nubian sandstone aquifer in the West Desert is of excellent quality in most areas and therefore is considered the main water resource. Rational use and reuse of water resources is imperative.

### 2.1.2 Agricultural Land Classification

The expansion in the agricultural land is carried out horizontally and vertically. The **horizontal expansion** requires reclaiming new areas, in addition to adopting new agricultural practices that match with the requirements of the growing crops in such new areas.

The horizontal expansion classifies the agricultural and cultivated land mainly into 3 categories:

1. The old lands.
2. The Oases (in Western desert)
3. The new lands.

The **old lands** are mainly located in the Nile valley and Delta. These are the main growing areas in Egypt that are characterized by complex yearlong cropping pattern. The richest crop production area is the Mid-Delta region due to the high quality of soil. The Northern Delta region is characterized by high salinity, especially near the Mediterranean Coast and lakes. Upper Egypt is characterized by arid weather; thus, certain types of crops are being grown there (as sugarcane).

The most famous **Oases** in the Western desert are Siwa (in the north section), Baharia and Frafra (in the central section), which are distinguished with artesian wells with high discharge of fresh water, since underground water is naturally flowing from the natural springs and from the deep and shallow underground water wells. Agriculture relies on underground water as the main water resource, for that rational use and reuse of water resources is imperative.

The **new lands** refer to the reclaimed areas since the construction of High Aswan Dam (HAD) in 1970. The new lands are located not only on the fringe of the old lands, but also in other areas outside the Nile valley and Delta, such as in the western desert. Although the new lands are generally speaking less fertile compared to the old lands, the reclaimed agricultural lands in the desert are characterized by having advanced technology. Crops in these new lands therefore tend to be higher value crops such as tree crops and vegetables (MoWRI, 2005).

On the other hand, the **vertical expansion** is carried out through crop intensification using high yielding varieties, and by cultivating the land more than once a year using suitable farming technologies. In addition, the crop diversification varies according to the climatic and soil conditions in different regions along the country.

The horizontal expansion was reported to show the cultivated area ranging from 5.68 million feddans in 1966 to 8.95 million feddans in 2013 (CAPMAS, 2015), while the development through reclamation between 2005 and 2013 was around 16,600 feddans only.

Furthermore, following the political changes in 2013 and the gradual accompanying stabilization in the country conditions, the Government of Egypt (GoE) embarked on applying the policy of horizontal expansion through a comprehensive development plan included the reclamation of about 1.5 million feddans, to be implemented in 3 phases of 0.5 million feddans each. Most of the project's areas will rely mainly on the underground water for agricultural purposes, where the total number of wells expected to be used is estimated to be around 4,800 wells. The full scale implementation of this project will require mobilization of around 4.38 billion $m^3$ from underground water annually (mostly from the Nubian sandstone and the post Nubian sandstone aquifers).

This national project is meant to increase the agriculture and cultivated area, contribute to reducing the food deficit and enhance the national food security, as well as offering new job opportunities for the youth.

### 2.1.3 Agricultural Landholdings and Tenure Structure

The landholding pattern underwent many changes since 1952, where reform laws were enacted and enforced to ensure equitable redistribution of landholdings (laws 178/1952, 127/1961 and 50/1969). These laws were followed by consecutive adjustment laws and enhancements necessary to regulate the relationship between the land owners (landlords) and the tenants.

**Landholding** in agriculture is defined as any area of land, regardless of its size, used totally or partially for plant, animal or fish production. Therefore, all lands managed by one holder that fall within the same district, regardless of its location, are considered as one farm (the Agricultural Census 1961). A landholder is defined as any natural or legal person who uses a farming land, whether by means of ownership, rent or both; and is administratively, financially and technically responsible for the farm (the Agricultural Census 1981–82).

The agricultural land tenure is a form of land use for producing crops. It bears various types of relationships among farmers and different weights as determined by the laws that regulate transfer of ownership titles and tenancy rights. In Egypt, the agricultural land tenure pattern takes one of three forms (Seyam & Bilassi, 1995):

1. **Land ownership:**
   The landlord (right of possession) and landholder (right of utilization) is the same person. Hence, this pattern is referred to as owned holding (OH).

2. **Mixed landholding:**
   Each of the landlord and the tenant has the right of possession for one part of land, but only the right of utilization of the other part of the land.

3. **Land rental:**
   TThe landlord preserves the right of possession, while the right of utilization goes to the tenant, based on a rental agreement. The rental holding (RH) takes one of 2 different forms in Egypt:

   - **Cash rental:**
     the tenant agrees with the landlord to pay at a fixed time a certain amount of money as rental fees for the land area stated in the contract. This form is the most common practice, especially in the old lands (Nile valley and delta).

   - **Crop-Sharing rental:**
     the tenant agrees with the landlord to pay a fixed percentage of the crops' yield of the land area stated in the contract, at its maturity (after harvest). The crop-sharing agreement is governed by the Agrarian Reform Laws (ARL) and takes one of the following two patterns:

     - **Crop and cost sharing:**
       the landlord provides the land and buildings, and shares half the costs of seeds, fertilizers, irrigation, pest

management, and harvesting and land tax. The tenant bears the cost of manpower, maintenance of irrigation and drainage canals, as well as half of other expenses. After harvest, the crops' yield is divided equally between the landlord and the tenant, provided that the share of the landlord should not exceed 50% after deducting all respective expenses as per the ARL.

- **Predetermined crop share:** the landlord receives a specific quantity of the crops' yield against the land rental. However, the ARL stated that the landlords' share should not exceed **7 times** the value of the land tax.

The share of each of these landholding patterns has developed over time. However, the owned landholding was the majority, while most of the rented cash holdings were more likely to be cash rentals rather crop sharing and other forms. Although the available data is until 1982 (Seyam & Bilassi, 1995), it is useful to have an overview of the landholding patterns as displayed in Figure 2.2

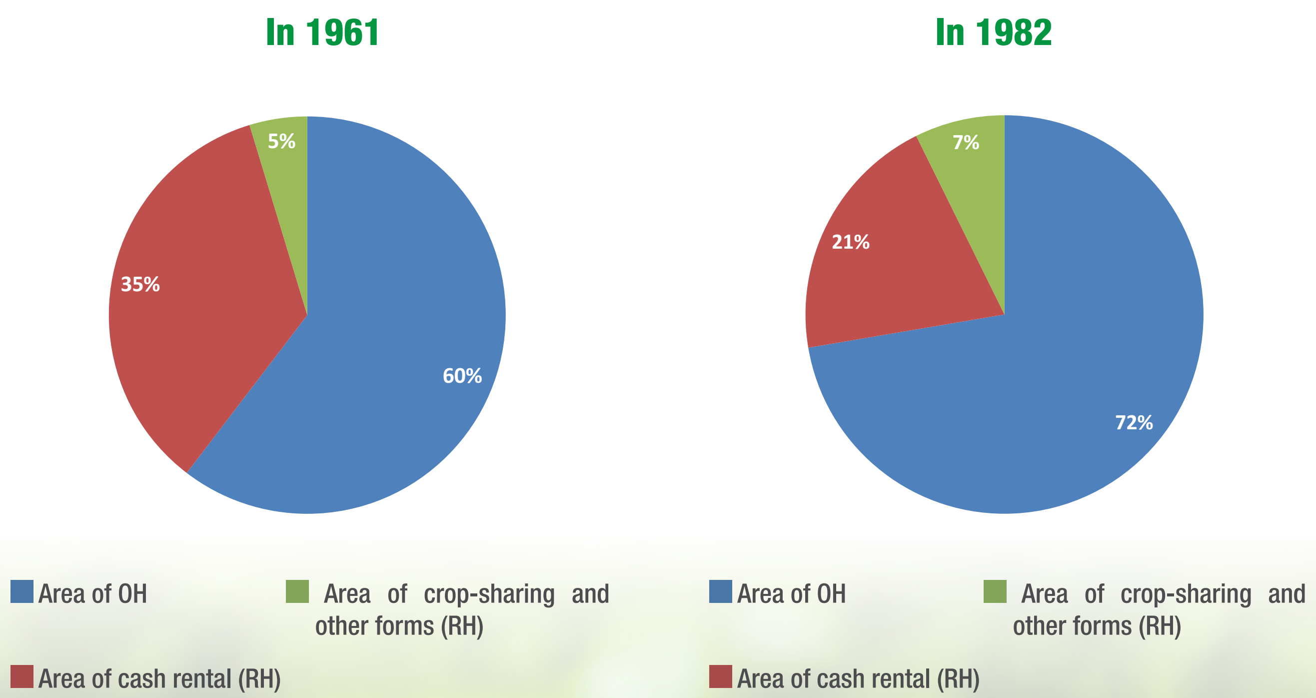


**Figure 2.2:** Changes in the agricultural land holding patterns between 1961 and 1982 (Seyam & Bilassi, 1995)

### 2.1.4 Agricultural Area and Fragmentation of Possession

One of the main characteristics of agricultural land in Egypt is fragmentation of possessions (land tenure), that one landholding could be scattered into a number of plots, either in the same village or in other villages in the same district. This is an important and influential factor in the decision making process and especially for converting from conventional pumps to solar water pumps (SWP) to cover the related costs.

Recent information (MoALR, 2010) shows a total agriculture area of around 9,082,531 feddans, which belongs to 4,421,810 landholder (possessions), making an average of almost two feddans per landholder. The majority of the cultivated area is irrigated using Nile River water (76.71%), while only 15.16% is using underground water for irrigation. Other sources used for irrigation are drainage water (0.90%), mixed water (4.47%), rain water (2.54%) and other sources (0.21%). However, we will focus on the first 2 sources of irrigation, for which SWP systems could be applied.

The pattern of landholding differs with regards to the method of irrigation, whether it is surface irrigation using Nile water or underground water, as shown in Figure 2.3 and Figure 2.4 respectively.

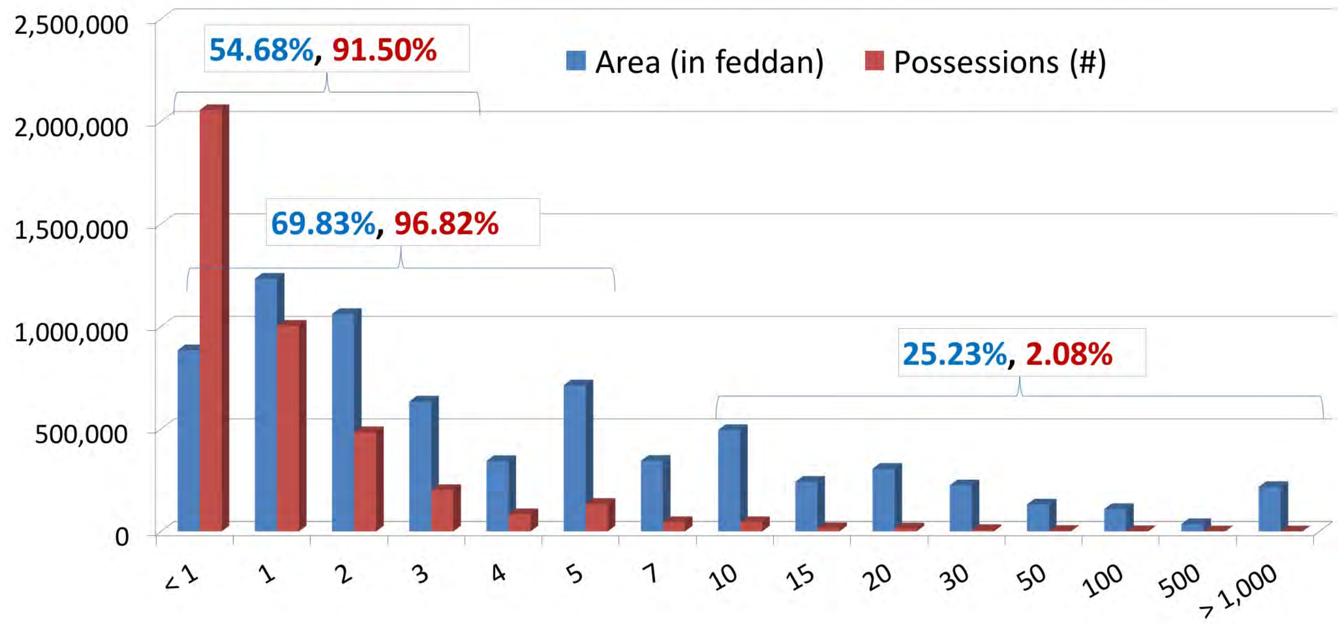


**Figure 2.3:** Categories of landholding (number of possessions) and areas (in feddans) using Nile water irrigation

From Figure 2.3, it is easy to notice that almost half of the landholdings (i.e. 50.23% of possession) are for an area less than one feddan (12.68% of the whole area), which add up to be around 75% of total possessions, if the area of one feddan is considered, for both categories correspond to around 30.37% of the whole area applying surface water. On the other hand, only 2% of the landholders occupy the categories equal to and above 10 feddans, which is equivalent to 25% of the total area relying on the Nile water for irrigation.

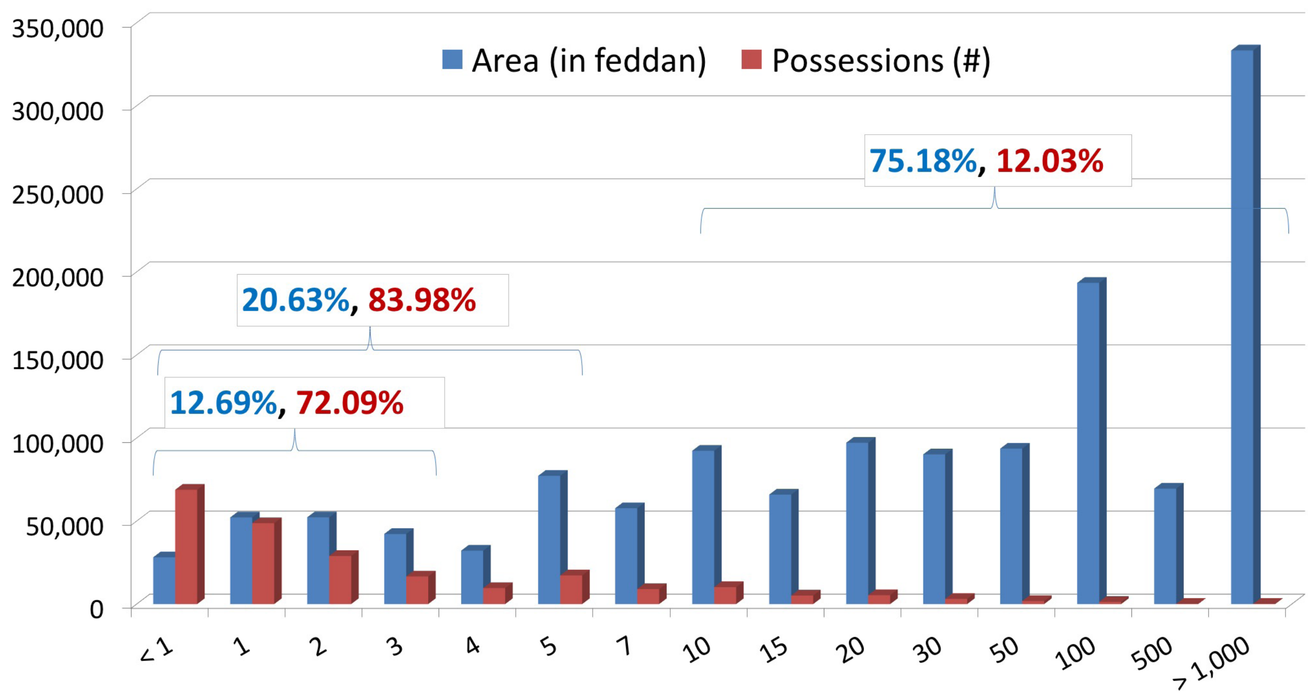


**Figure 2.4:** Categories of landholding (number of possessions) and areas (in feddans) using underground water irrigation

The degree of fragmentation of possessions prevails also where underground water is used for irrigation. Figure 2.4 shows that 84% of landholders possess areas less than and equal to five feddans, which is equivalent to around 21% of the total area irrigated by underground water. On the other hands, around 75% of this area is for the categories above 10 feddans and belongs to around 12% of the landholders.

Both figures and related numbers give a clear indication for the high degree of fragmentation of the cultivated areas among landholdings, especially for the categories less than five feddans. This is one of the main challenges for upscaling the market of SWP in Egypt.

All these numbers are based on areas for which legal possessions are registered by the MoALR. However, it was announced recently that other areas were found to be running agriculture activities without holding legal possession documents. Unfortunately, no accurate numbers are available, and different verbal resources indicates that these areas could be something between 600,000 and up to four million feddans scattered in different regions of the country! This is why legalizing the status of these possessions is one of the priority issues for the MoALR and the MoWRI[2].

2 Meeting with high level official in MoWRI (Dr Sameh Sakr, May 2017).

## 2.2 Overview of the Main Water Resources

Egypt is one of the countries facing great challenges due to its limited water resources, where the dependency ratio of 96.9% of the total renewable water resources flowing into the country from neighbouring countries is one of the world's highest (Worldbank, 2007). Also, the MoWRI stated that the main and almost exclusive source of water in Egypt is the Nile River (MoWRI, 2014). The Nile water agreement with Nile Basin Countries allocates a fixed share of 55.5 billion $m^3$ per year to Egypt. This amount is guaranteed by the multi-year regulatory capacity provided by the HAD.

### 2.2.1 History and Background Information

Water resources in Egypt are represented with the quota from the Nile water; the limited amount of rainfall on the coastal areas; the shallow and renewable underground water reservoirs in the Nile Valley, the Nile Delta and the coastal strip; and the deep (mostly non-renewable) underground water in the eastern desert, the western desert and Sinai. The non-traditional water resources include reuse of drainage and wastewater, and desalination of seawater and brackish underground water.

After the completion of the HAD in 1968, Egypt started a new era of development through more controllable Nile water releases to different water users. Water users include agriculture, municipalities, industry, navigation, hydropower generation, and fisheries. Navigation and hydropower generation are non-consumptive uses, as water releases are only needed to maintain their operating water levels. Recently, water demand for municipal and industrial sectors started to compete with agricultural water demand due to the rapidly growing population.

The schematic shown in Figure 2.5 presents a simplified overview of Egypt's sources and uses of water resources.

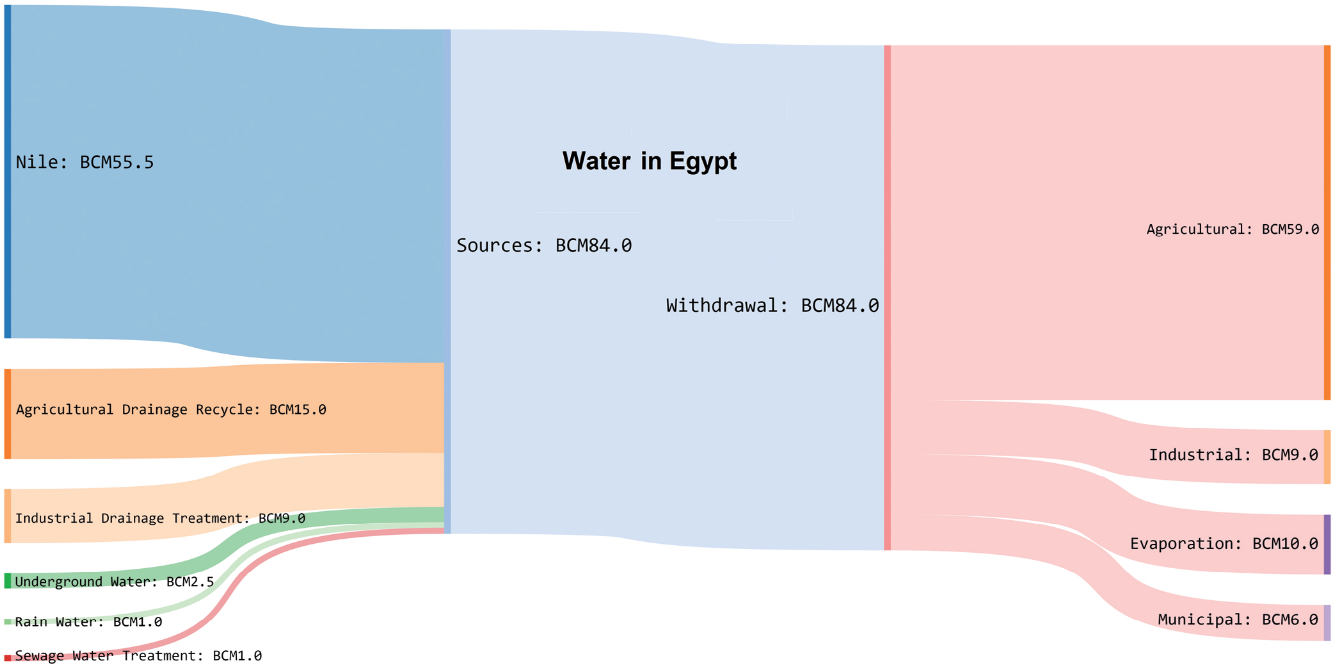


**Figure 2.5:** Main water sources and withdrawal in Egypt (in Billion Cubic Meters (BCM))

According to the (Worldbank, 2007), there are six main sources of water which are the Nile river (55.5 BCM, 66%), agriculture drainage recycling (15.0 BCM, 18%), industrial water treatment (9.0 BCM, 11%), underground water (2.5 BCM, 3%), rain water (1.0 BCM, 1%) and sewage water treatment (1.0 BCM, 1%). A summary of the main water resources (supply) and withdrawal (demand) is illustrated in Figure 2.6.

The total of 84 BCM is mainly withdrawn by four main sectors, which are the agriculture sector (59.0 BCM, 70.2%), the industrial sector (9.0 BCM, 10.7%), the municipalities (6.0 BCM, 7.1%) and as evaporation losses (10.0 BCM, 11.9%) (Zaki & Hamdan, 2016). Therefore, the agricultural sector is considered the largest water-consuming sector of the Nile water.

In this regard, it is important to note that water used for agricultural purposes is not priced, that farmers are not charged for their volumetric consumption or their choice of crop. In contrary, water is a farmers' right for cultivation and is considered as their entitlement. Accordingly, the cost of agricultural water is that of its extraction, distribution, and delivery to the farms ( (AfDB, 2014).

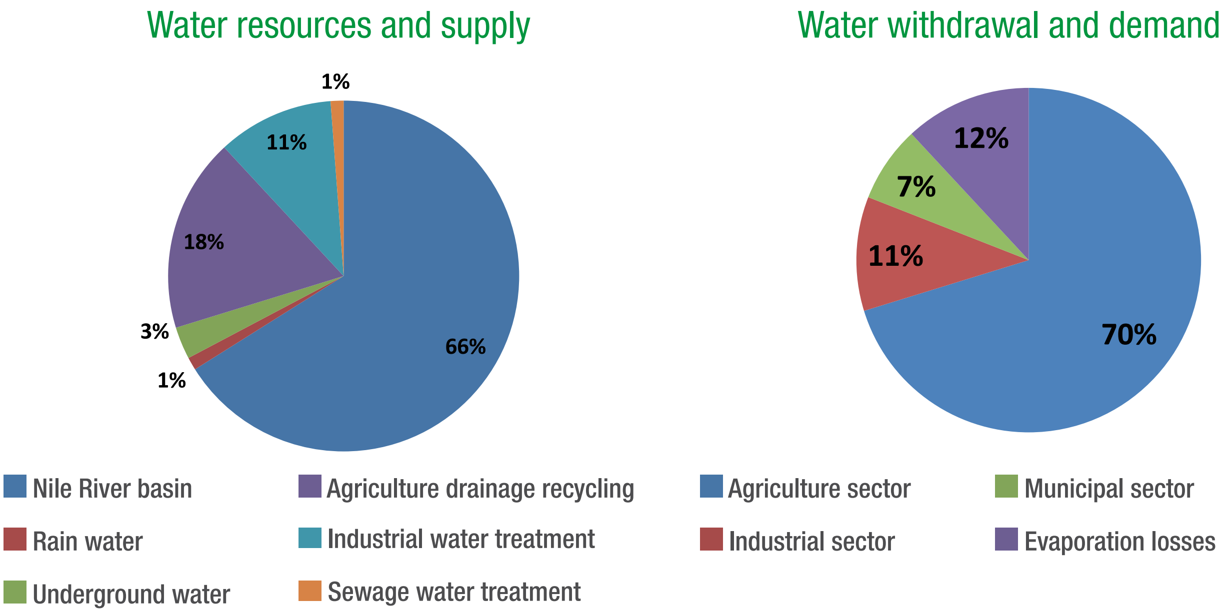


**Figure 2.6:** Main water resources and withdrawal

Rainfall occurs only in winter and is rather in the form of scattered showers. The average annual amount of effectively utilized rainfall water is estimated to be 1.0 billion m$^3$ per year. This amount cannot be considered a reliable source of water due to high spatial and temporal variability in different regions of the country.

The reuse of non-conventional water sources such as agricultural drainage water and treated sewage water cannot be added to Egypt's fresh water resources. In fact, using these sources is a recycling process of the previously used Nile fresh water in such a way that improves the overall efficiency of the water distribution system. The amount of water that returns to drains from irrigated lands is relatively high (about 25 to 30%). The total amount of reused water is estimated to be 11.1 billion m$^3$ in 2013-2014. The reuse practices increase the overall efficiency of the system as comparable to the efficiency of modern irrigation systems.

## 2.2.2 Sources for Surface Water

The Nile River is the main source of water in Egypt, with an overall dependency ratio of 96.9%, which is the highest among its neighbour countries (Worldbank, 2007). Its annual share in the Nile water is 55.5 BCM, as an agreed quote as regulated by an international treaty with the Nile Basin countries.

## 2.2.3 Sources for Underground Water

It refers to water found at various depths under the ground surface, filling the pores, cracks and spaces in the soil, sand, sediment or rock. It is stored in and moves slowly through formations of soil, sand and rocks called aquifers. In total, there are 80,000 wells spread overall Egypt, not all are operating all the time though. Around 3,100 of these wells (~4% of the total number) are under governmental control and are being managed by the "Underground Water Sector" of the MoWRI[3].

The main aquifers in Egypt are clearly illustrated in Figure 2.7, where these aquifers are classified according to its hydrological characteristics as follows:

1. Nile Valley and Delta aquifers
2. Coastal aquifer: along the northern coast.
3. Nubian sandstone aquifer: contains about 150,000 billion $m^3$ of fossil water at depths reaching 2000 m.
4. Moghra aquifer
5. Tertiary aquifer
6. Carbonate aquifers (rocks complex; karstfied rocks and limestones)
7. Fissured basement complex aquifers (hard rocks)
8. Aquiclude aquifer (clay or shale)

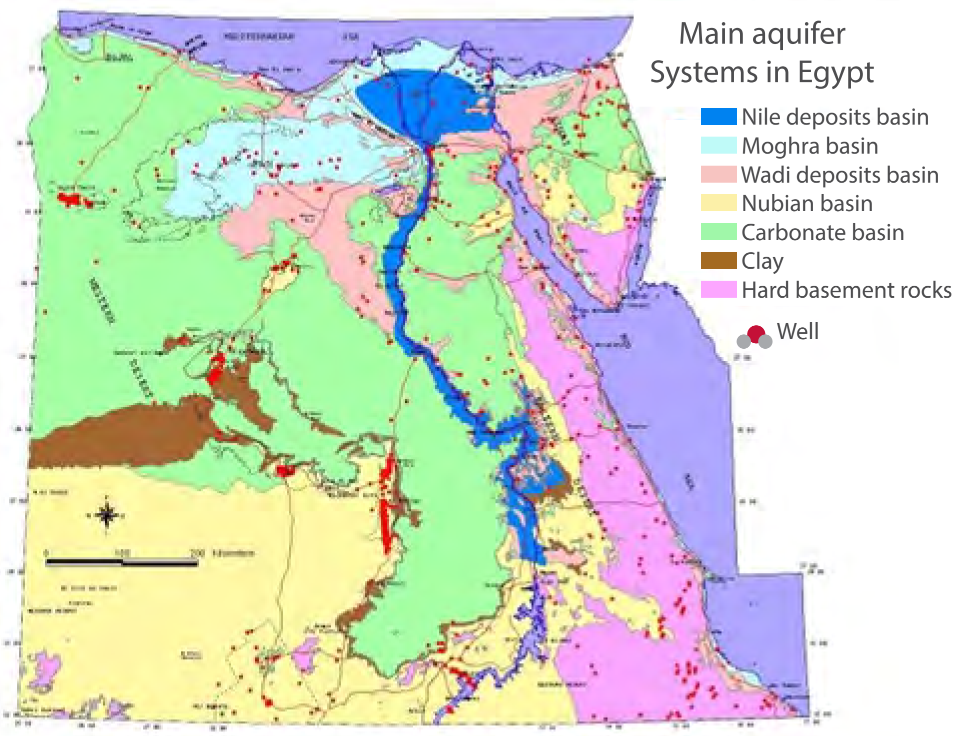


**Figure 2.7:** Main aquifer system in Egypt (Elnashar, 2014)

[3] Meeting with high level official in MoWRI (Dr Sameh Sakr, May 2017)

These main aquifers are formed either of granular rock; as the Nile valley and delta aquifer, together with the coastal, Nubian, Moghra and Teriary aquifers, which are in sandy gravel formation, or of limestone and hard rocks like the Carbonate and fissured basement aquifers, or of clay or shale formation as in the aquiclude aquifer (Tahlawi, et al., 2008).

The Nile Valley and Delta are mainly Nile deposits with a total storage capacity of 200 and 300 billion $m^3$ respectively. These aquifers are characterized by its high productivity rate of around 100-300 $m^3$ per hour, with relatively shallow wells at relatively low pumping cost. The annual withdrawal rate was estimated to be around 6.13 billion $m^3$ per year (Hegazy & El-Bagouri, 2002), which is considered within the safe withdrawal margin to ensure the sustainability of this aquifer (MoWRI, 2010).

The underground water in the aquifers located in the Western Desert and Sinai is mostly deep and non-renewable. The total underground water volume has been estimated at about 40,000 billion $m^3$. However, current abstraction is estimated to be 2.0 billion $m^3$ per year (MoWRI, 2014). The main obstacles in utilizing this huge resource are the great depths of these aquifers (up to 1,500 m in some areas) and the deteriorating water quality at the increasing depths.

However, there might be a possibility of using the low salinity brackish underground water to irrigate certain seasonal crops. This water is available at shallow depths in the Western and Eastern Deserts and at the borders of the Nile valley. The average salinity of such water varies from 3,000 to 12,000 ppm. Renewable energy sources (like solar and wind) could be used in the treatment process to minimize the cost and increase its economic value. This source will supplement rainfall to increase land productivity by cultivating two crops per year instead of one.

Shallow underground water in the Nile aquifer cannot be considered a separate source of water from the Nile River, since this aquifer is recharged only by seepage losses from the Nile, the irrigation canals and drains and percolation losses from irrigated lands. Hence, its yield must not be added to Egypt's total water resources. Therefore, it is considered as a reservoir in the Nile river system with a huge capacity, but with only 7.5 billion $m^3$ per year rechargeable live storage. The abstraction from this aquifer was estimated at 6.7 billion $m^3$ in 2013.

Accordingly, after considering the efficient and sustainable use of underground water, three main important factors (and constraints) to be considered with regards to the underground water irrigation are: (1) the cost of drilling, (2) the capacity of SWP required to uplift water to the surface, (3) as well as the quality of the underground water. Since the MoWRI is keen on water sustainability, relevant studies were done to ensure the sustainability of discharge of underground water and accordingly respective measure are being taken to prevent over charging these wells.

In this regards, the MoWRI proposed a methodology to ensure the sustainability of the groundwater aquifers, in which the MoWRI will design the proposed wells for each area including the number of wells, space between each well, wells' depth and maximum allowed discharge, the depth of pumps' setting and the source of energy. From the MoWRI viewpoint, using SWP is preferred, especially that the intermittence nature of solar PV (limited to availability of sunshine) offers an optimal control and is therefore an advantage in favour of the sustainability of underground water. However, the MoWRI also proposed limiting the hours of wells' operations to 10 hours per day in case of using other sources of energy (like diesel generators or electricity grid).

Furthermore, in order to ensure sustainability of aquifers, the MoWRI is to implement groundwater monitoring system for the water levels and quality as a preventive measure and wells will be run alternately to allow for aquifers' recovery. The MoWRI is responsible for the wells' operations through an automated control system, which is programmed according to crop requirement. Accordingly, crop patterns must be predetermined and modern irrigation systems applied, in order to calculate the allowed withdrawal rate per day for the respective wells.

Sometimes, the irrigation systems could also be optimized to combine more than one energy system (i.e. hybrid system), in order to maximize the overall benefits through balancing the systems' cost and robustness. This compromise could be valid for new communities, as well as for large farms using multi-well hybrid system as illustrated in Figure 2.8.

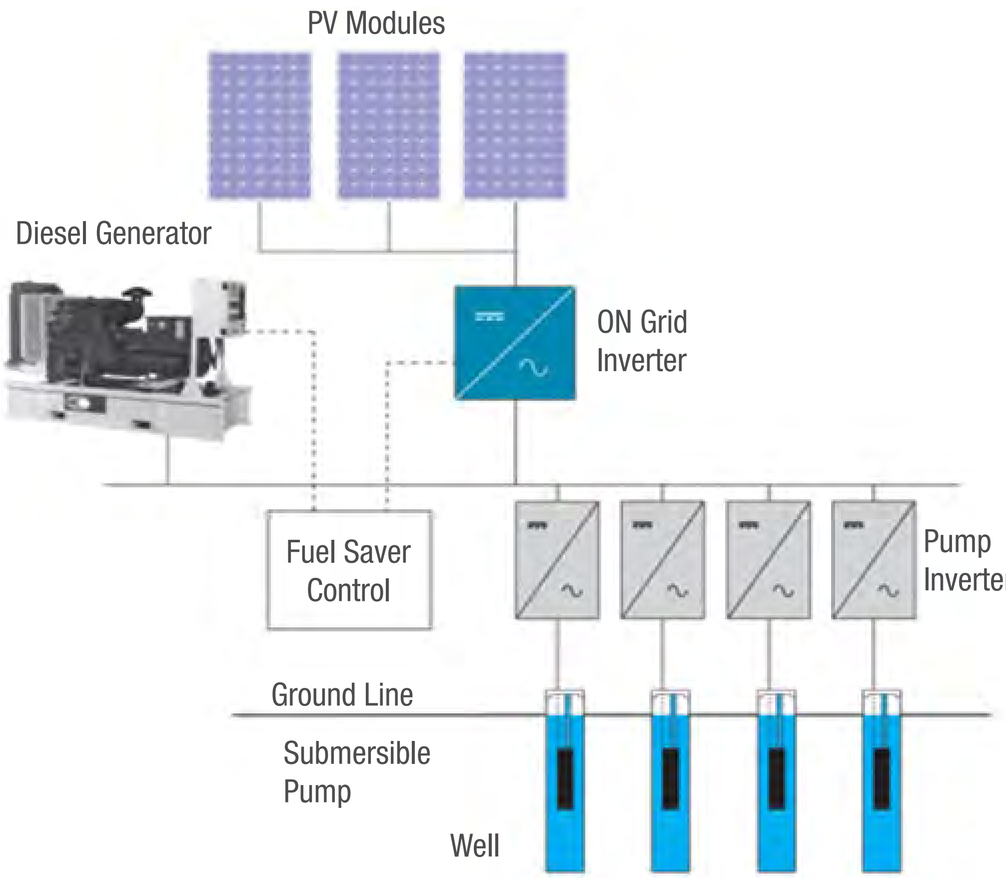


**Figure 2.8:** Multi-well hybrid system (solar PV and diesel generator)

In Moghra area, implementations of SWP systems have been carried out successfully in parallel with diesel (hybrid systems) due to concerns of the investors. Another example in Farafrah oasis, where a solar PV station of capacity 4 MW and a diesel station of capacity 16 MW are operating in parallel to serve 10,000 feddan and a community of three villages (one service community and two residential communities, each has 2,000 farm house). The latter is a successful case for operating hybrid systems smoothly to maximize the overall benefits[4]. Furthermore, according to media announcements, there is a huge project in Moghra area using 20 PV plants to power water pumping and farming activities for more than 12,000 feddans for Jojoba plant.

Furthermore, a successful example in Eldakhla Oasis extends to highlight the importance of commitment of all beneficiaries in sharing responsibility, where the "Water Users Association" adopted the concept of revolving funds to cover the operation and maintenance expenses of SWP systems, while only one person is in charge of the well and this role is rotating among all beneficiaries.

4 Meeting with high level officials in Alreef Almasry

## 2.3 Irrigation Sector and Common Practices

The irrigation in Egypt is a closed system, with the Nile River as the main source and inlet for water used in irrigation.

### 2.3.1 Structure of Irrigation Network

Egypt operates an ancient and spatially complex irrigation system, through which more than 70% of the Nile water resources are used for agriculture purposes. The schematic shown in Figure 2.9 presents a highly simplified diagram for the irrigation water network in Egypt.

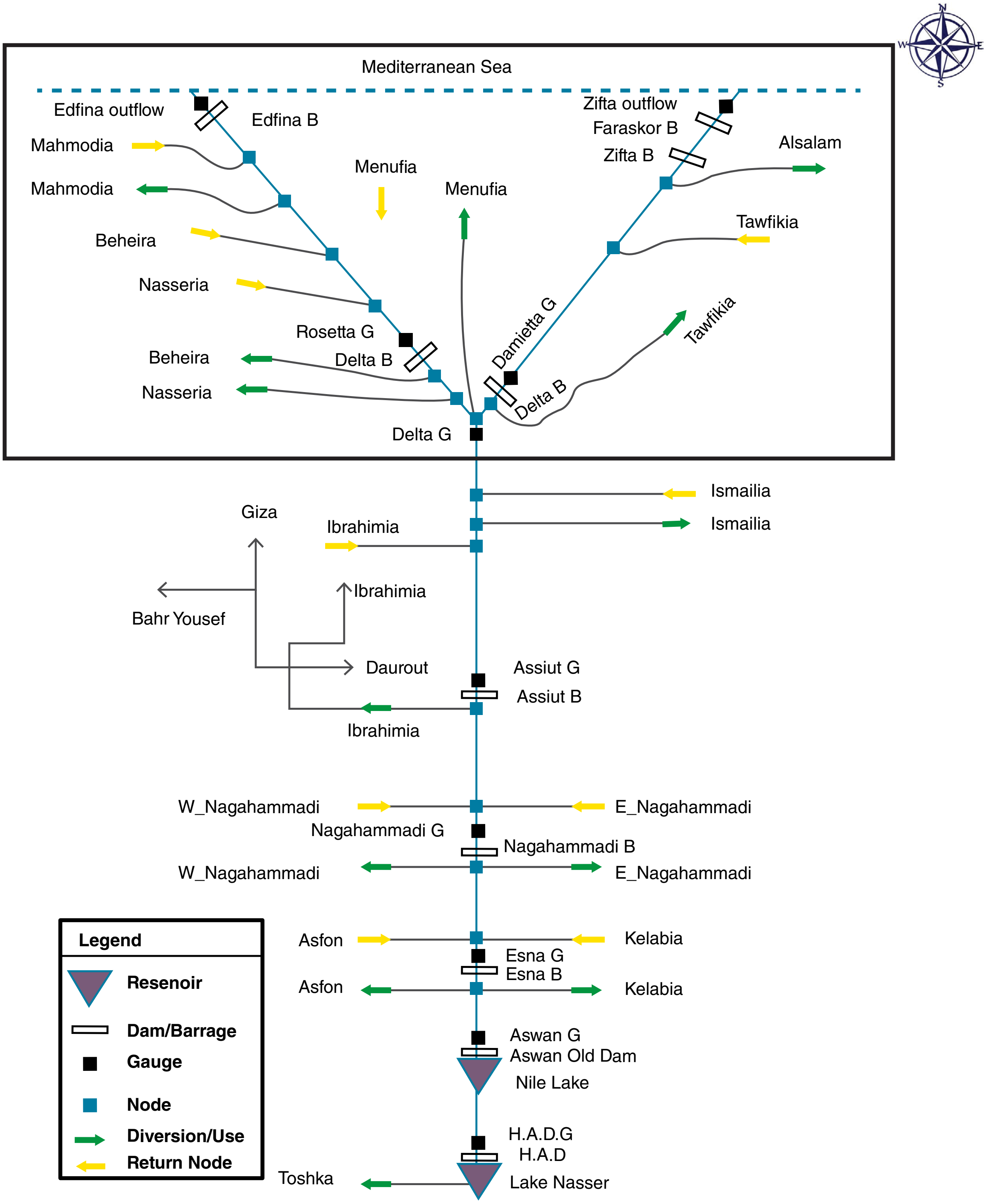


**Figure 2.9:** Schematic diagram for the irrigation water network of Egypt (River stem and main canals)

The system hierarchy begins with the main-stem of the Nile River. The main (principal) canals' diversions shown in the schematic include Asfon, Kelabia, East Naga-Hammadi and West Naga-hammadi in Upper Egypt, while the Toshka canal takes water directly from Lake Nasser. Middle Egypt has two main canals; the Ibrahimia canal divides its water between many canals to serve irrigation in the Assiut region; while the Ismailia canal irrigates the Suez and Elsharkia regions. In Lower Egypt, downstream of the Delta gauge, the Nile splits into two branches, Rosetta and Damietta, so creating the Nile Delta. The Rosetta branch includes the Menufia, Beheira, Nasser and Mahmodia canals, while the Damietta branch includes the Tawfikia and Alsalam canals.

These main (principal) canals receive water directly from the Nile, then deliver to branch canals and distributary canals. The minor canals (also known as "mesqas") receive water from the branch or distributary canals, and then deliver the water either directly to the fields or into smaller outlets (also known as "Marwas"), which are private deliveries from mesqas that convey water to fields located at a distance from the Mesqa, as illustrated in Figure 2.10.

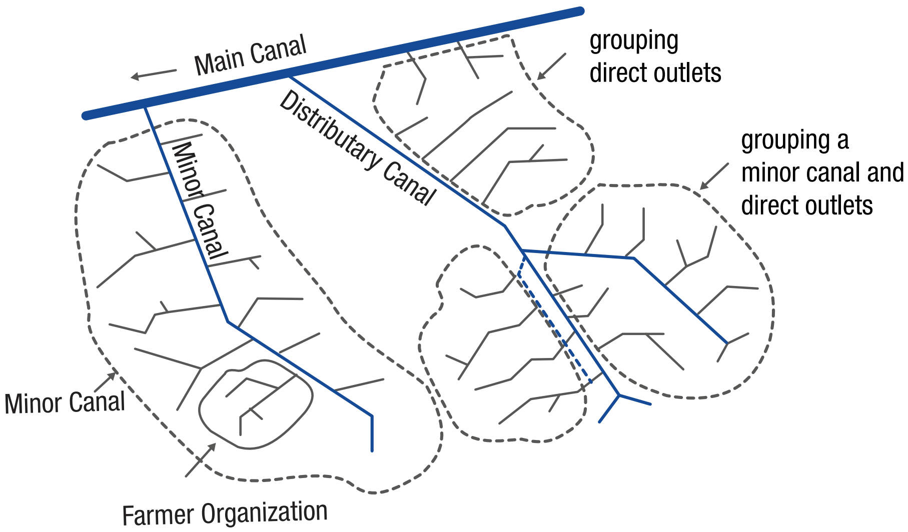


**Figure 2.10:** Canal network system in Egypt

The gravity system is the main technique for carrying water along this irrigation system, from the Nile to the fields. As illustrated in Figure 2.11, the flow of water is regulated through barrages (diversion regulator) in the Nile River and is directed to the main canals through head regulators and intermediate regulators along the main canals. Head regulators are also used to direct the water flow to the branch canals. Branch canal head regulators are generally equipped with lifting gates, and regulation of water deliveries is achieved by adjusting gates to maintain target downstream water levels (Wolters, et al., 2016). From the minor canals or smaller outlet, escape regulators are used to dump the water into the drains.

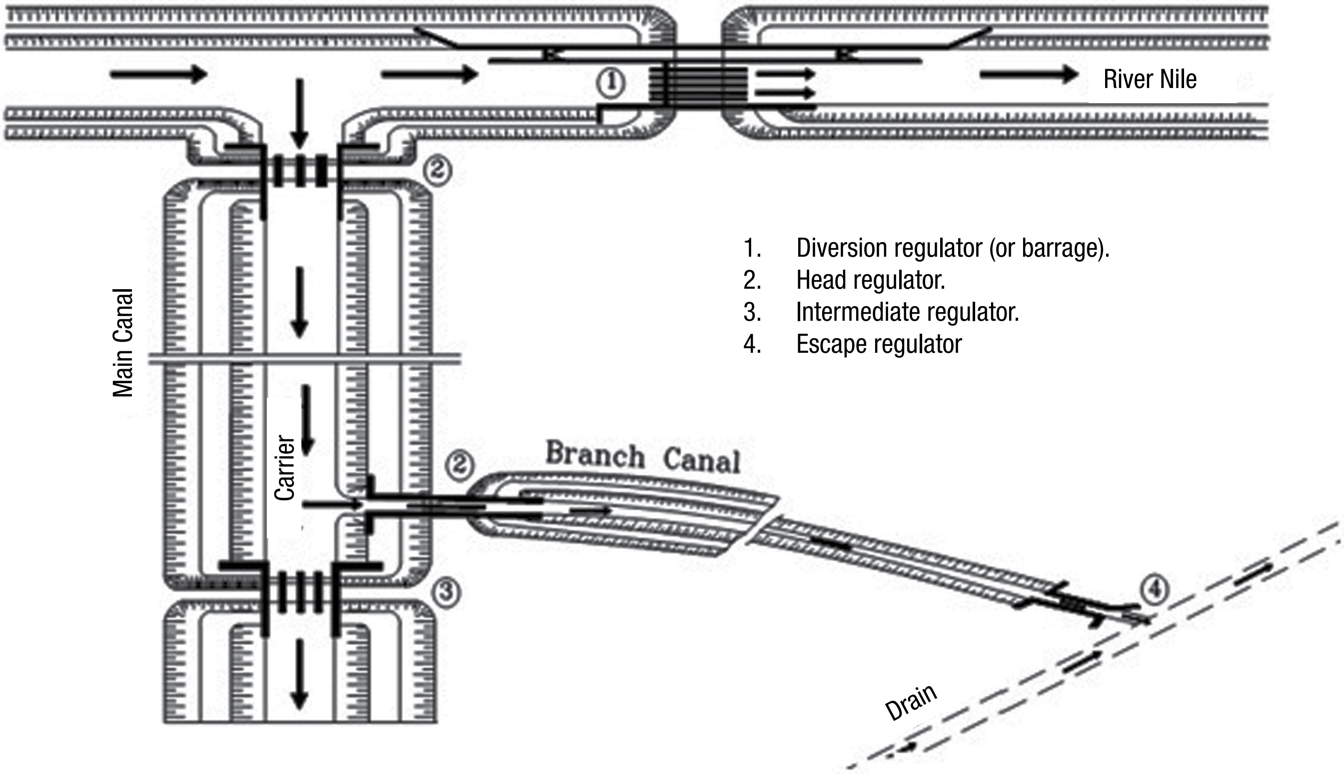


**Figure 2.11:** Layout for different head regulators for carrying Nile water for irrigation

Because farmers lack confidence in the upstream control-rotational irrigation system, they tend to over-irrigate, particularly head-end farmers, as an insurance against the uncertainty of the irrigation water supply. Thus, they reduce water availability to tail-end farmers who, in turn, adopt a coping strategy that involves the reuse of drainage water even if it is saline, which is referred to as "unofficial reuse" (Wolters, et al., 2016).

In general, there are about 30,000 km of public canals, 80,000 km of mesqas and drains and **670 large pumping stations** for irrigation and dumping drainage water either into the sea, lakes or canals. The management responsibility of these canals is shared between the MoWRI and MoALR. The MoWRI is responsible for the process until the water reaches the minor canals (mesqas). Starting from the minor canals, the MoALR is in charge until the water reaches its destination and irrigates the fields.

With regards to the common irrigation practice, water pumps are used to lift water from the branch and distributary canals to the minor canals (mesqas) serving a certain district or village. These pumps are fixed and its capacity is relatively big compared to the water pumps used for irrigating the fields. An example of this water lifting pump of capacity 16 Horse Power (hp) is illustrated in Figure 2.12.


**Figure 2.12:** fixed water pump for lifting water from the canals to minor canals.

Furthermore, water pumps are needed to irrigate the fields, either from the minor canals or water outlets or even from shared reservoirs. For this purpose, water pumps of capacities ranging from 6 hp to 16 hp are used to lift water for about 0.5 m to 1.5 m. These water pumps can be fixed or portable, a clear from Figure 2.13. Since the price of water pumps is expensive and not all crops require daily irrigation, the farmers' associations or cooperatives usually possess a few portable (mobile) water pumps, which the micro scale farmers can rent against charges per hour of use.

**Figure 2.13:** Portable (mobile) water pump of capacity 6 hp (operated by diesel)

According to the MoALR (2016), there are a total number of 957,534 water pumps being used for irrigation in different governorates, where 82% are fixed and 18% are portable as illustrated in Figure 2.14.

Since the next section (2.3.2) refers to the different methods of irrigation depending on the source of water used (whether river-based or deep wells), it is important to refer to the share of the water pumps used to extract water from deep wells. This is illustrated in Figure 2.15.

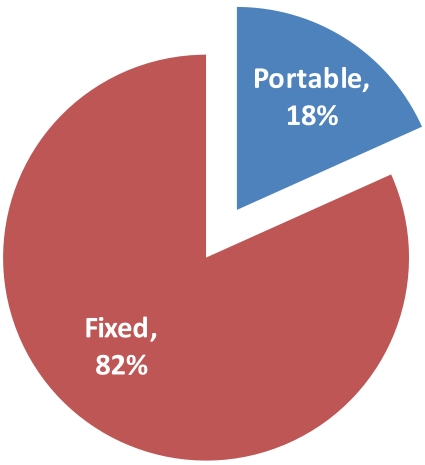


**Figure 2.14:** Share of fixed and portable water pumps in all governorates in 2015 (MoALR, 2016)

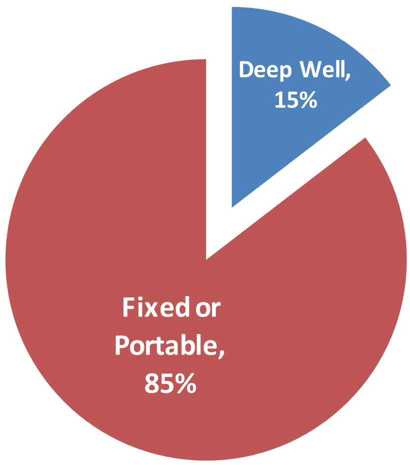


**Figure 2.15:** Share of deep well compared to fixed and portable water pumps in all governorates in 2015 (MoALR, 2016)

Furthermore, it is important to refer to the different capacities used for both, the fixed and portable water pumps, which are illustrated in Figure 2.16.

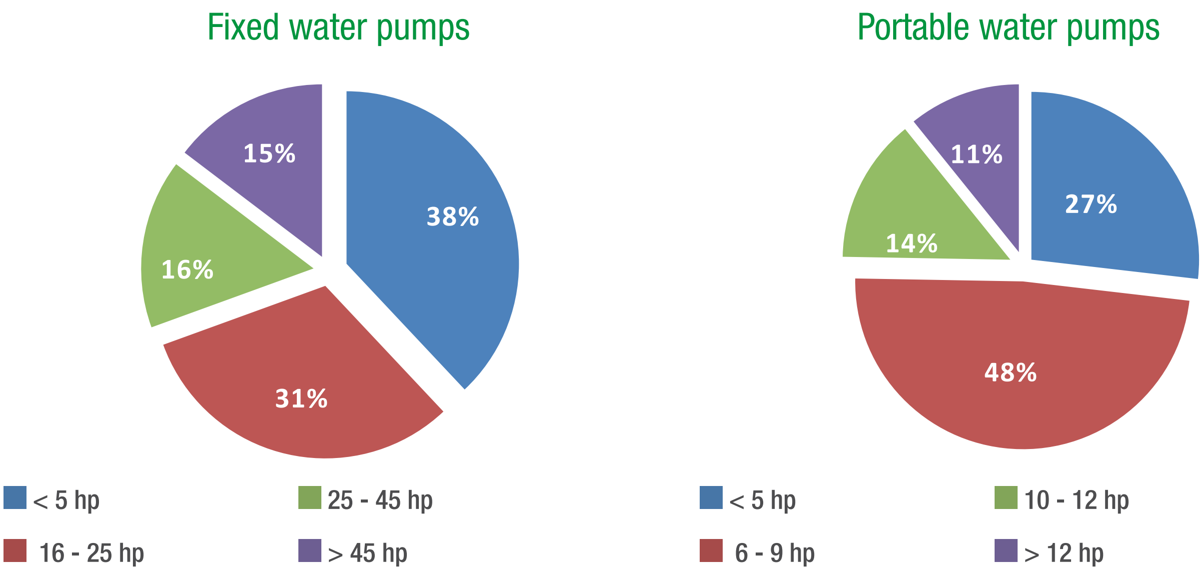


**Figure 2.16:** Different capacities for the fixed and portable water pumps

This section presented a brief on the common practices using the conventional energy (diesel), which could be reasonable target market for SWP systems. More details about the technical components of the SWPs will be discussed later under section 3.3.

## 2.3.2 Common Irrigation Practices

The dominant irrigation method is that relying on surface water irrigation, which covers approximately 83% of the irrigated areas and is considered the common practice in the old lands combined with water lifting systems (including water pumps). The rest lies under sprinkler (12.5%) and drip (4.5%) irrigation (both are sometimes referred to as pressurized irrigation), which is compulsory by law in the new lands and is especially suitable for the new lands on the fringe of the Nile valley and Delta, as well as for the mostly sandy soil in those areas.

### 2.3.2.1. Surface Water Flood Irrigation

This represents the traditional irrigation method especially in the old lands, often referred to as river-based irrigation. The schematic presented in Figure 2.9 and Figure 2.10 are used mainly for the flood irrigation. On average, each feddan is usually irrigated by 20 to 30 $m^3$ per day. This system is valid for almost all of the old lands located in the Nile valley and Delta, where flood irrigation is the common practice. This wide spread implementation might be due to its low capital cost, no special technical experience regarding operation and maintenance is needed and no specific equipment is required as well as the long practical background among local farmers regarding usage of such system.

On the other hand, flood irrigation has the lowest irrigation efficiency of 60% compared to drip and sprinkler irrigation. Deep percolation particularly in the upper part of the irrigated field as well as the less uniformity of irrigation water above soil surface are the main causes of the lower efficiency of flood irrigation. On average, losses of irrigation water under this method is about 45% causing several acute problems such as leaching of nutrient elements and raising of water table. Consequently, reduction in crop yield, crop water and/or fertilizer productivity could be predicted.

The branch and distributary canals system are operated according to agricultural rotation principal. There are two systems of rotation; two-turn rotation and three-turn rotation, as simplified in Figure 2.17.

Under the two-turn rotation, the canal system is divided into two groups. Each canal group is opened for seven days and closed for another seven days resulting in a length of irrigation interval of 14 days. Under the three-turn rotation, the canal system is divided into three groups. Each group is opened for five days and closed for another 10 days giving an irrigation interval of 15 days. [The rotation system for rice is usually two-turn rotation with four days on and four days off]. At the mesqa, distributaries receive water according to a rotation schedule. Flood irrigation by rotation may give poor results and if a surface method must be used, sandier soils should be irrigated more frequently.

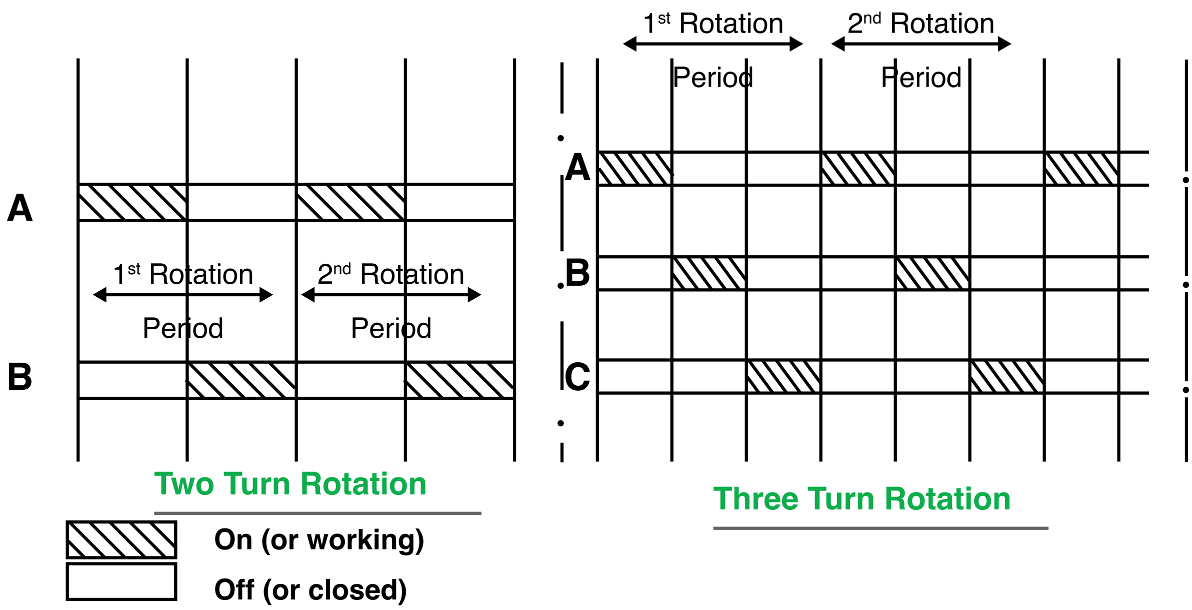


**Figure 2.17:** Two-turn versus three-turn rotation systems

From the MoWRI perspective, the ability to use time as an operating variable in the rotation system allows operating staff to compensate for any surpluses or deficits arising from the imprecision of the discharge regulation, and in particular to deal with "emergency" shortages on individual canals (Wolters, et al., 2016).

The flooding surface irrigation system use a cascade of pumping stations from the main canals passing through branch and distribution canals reaching to the fields, with a total lift of up to 50 m, in addition to the water pumps used for furrows irrigation. Accordingly, the main components of the flood irrigation system include the Nile River, the irrigation networks (including barrages and reservoirs), as well as the lifting system (including water pumps) and drainage system. A picture of a typical water pump used for lifting surface water is shown in Figure 2.18

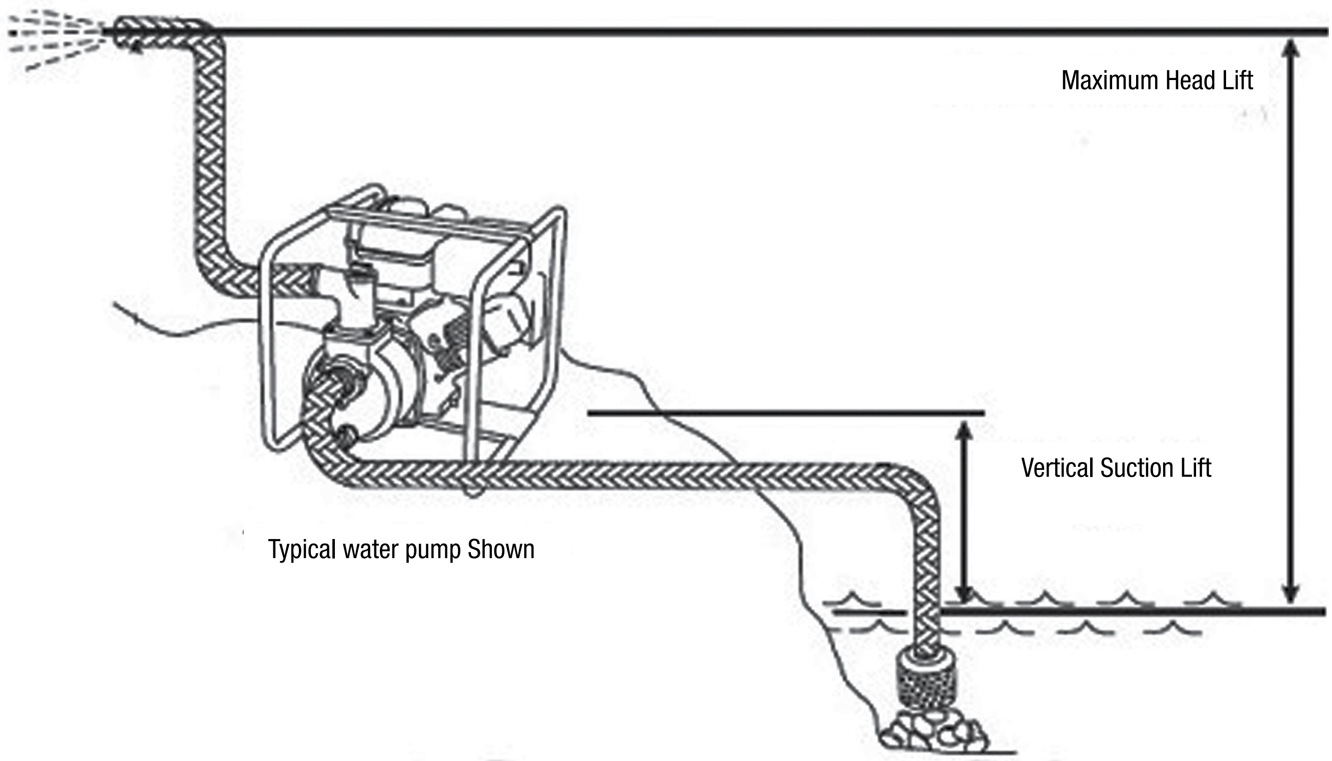


**Figure 2.18:** Water pump for lifting surface water to minor canals, smaller outlets or to the fields.

The fields located at the canals' tail-end are more likely to suffer from water shortage due to improper maintenance of the canals or growing crop patterns that require more irrigation than that of the canal's discharge. In this case, these fields could be irrigated from agriculture drains or using the shallow underground water aquifer to compensate this shortage.

### 2.3.2.2. Drip Irrigation

Drip irrigation is a form of irrigation that saves water and fertilizer by allowing water to drip slowly to the roots of many different plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters without any rotation. A layout for the drip irrigation system is shown in Figure 2.19.

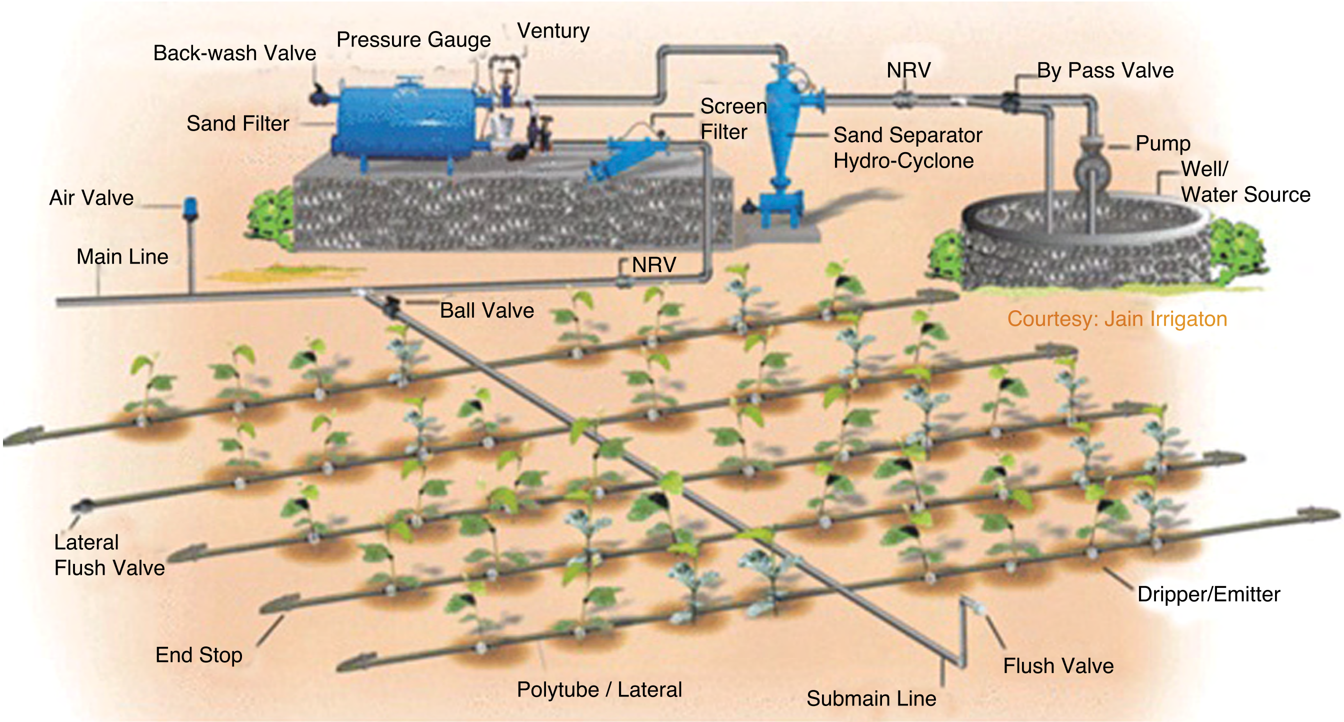


**Figure 2.19:** Layout for the drip irrigation system and its components

The system consists of pump unit, control head, main and sub-main lines, laterals and emitters or dripper.

The **pump unit** takes water from the source and provides the right pressure for delivery into the pipe system.

The **control head** consists of valves to control the discharge and pressure in the entire system. It may also have filters to clear the water. Common types of filter include screen filters and graded sand filters which remove fine material suspended in the water. Some control head units contain a fertilizer or nutrient tank. These slowly add a measured dose of fertilizer into the water during irrigation. This is one of the major advantages of drip irrigation over other methods.

The **mainline, submains and laterals** supply water from the control head into the fields. They are usually made from PVC or polyethylene hose and should be buried underground because they easily degrade when exposed to direct solar radiation. Lateral pipes are usually 13 to 32 mm diameter.

The **emitters** are devices used to supply very low flow rates (less than 10-15 l/hr) to the top soil; water drips to the root zone through small holes in the emitters, which are placed near the crops on the soil surface. They are usually spaced more than one meter apart with one or more emitters used for a single plant such as a tree. Water moves both sideways and downwards away from the point of application to form a "bulb" of wet soil. Also, it may be placed below the surface in order to protect the network from ultraviolet radiation. For row crops, more closely spaced emitters may be used to wet a strip of soil. Many different emitter designs have been produced in recent years. The basis of design is to produce an emitter which will provide a specified constant discharge which does not vary much with pressure changes, and does not block easily.

## 2.3.2.3. Sprinkler Irrigation

In the sprinkler method of irrigation, water is applied above the ground surface as a spray somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping, although it may be by gravity if the water source is high enough above the area to be irrigated. The irrigation water is distributed to the field through pipelines. The pressure varies from 0.70 to 20 m for a flow rate between 0.7 and 100 $m^3$ per hour respectively.

The sprinkler system includes the sprinkler, the stand pipe, the lateral pipe, the main line pipe and often the pumping plant.

The **pump** unit is usually a centrifugal pump which takes water from the source and provides adequate pressure for delivery into the pipe system

The **mainline and sub-mainlines** are pipes which deliver water from the pump to the laterals. In some cases these pipelines are permanent and are laid on the soil surface or buried underground. In other cases they are temporary, and can be moved from field to field. The main pipe materials used include asbestos cement, plastic or aluminium alloy.

The **laterals** deliver water from the mainline or sub mainlines to the sprinklers. They can be permanent but more often they are portable and made of aluminium alloy or plastic so that they can be moved easily. A sprinkler system using two laterals is shown in Figure 2.20.

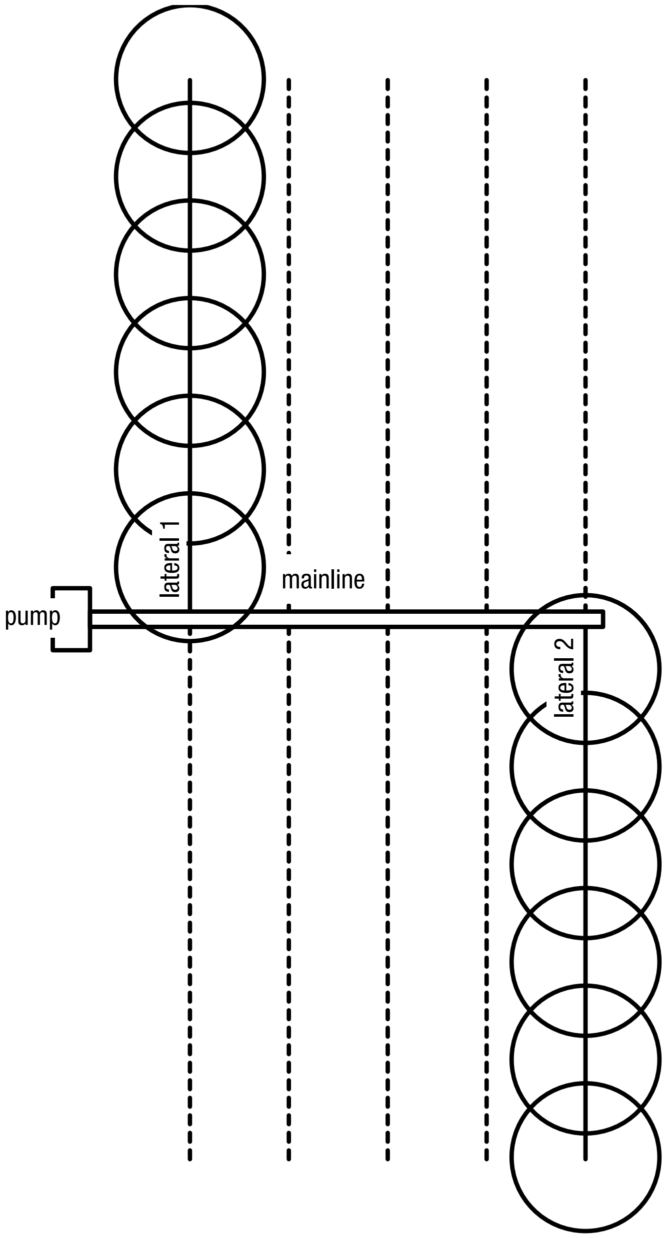


**Figure 2.20:** Sprinkler irrigation system using two laterals (manually moved)

The system consists of lightweight aluminium or plastic pipes which are moved by hand. The rotary sprinklers are usually spaced 9 – 24 m apart along the lateral which is normally 5 - 12.5 cm in diameter. The lateral pipe is located in the field until the irrigation is complete. The pump is then switched off and the lateral is disconnected from the mainline and moved to the next location. It is re-assembled and connected to the mainline and the irrigation begins again. The lateral can be moved one to four times a day. It is gradually moved around the field until the whole field is irrigated. This is the simplest of all systems.

### 2.3.3 Drainage System and Network

An intensive open drainage network was constructed along the Nile system downstream HAD in order to transfer the excess irrigation water safely to the Mediterranean Sea and terminal lakes through drainage canals at the end of each catchment as illustrated earlier in Figure 2.11. This drainage network helped in improving the agricultural conditions such as lowering water table and leaching soil, which consequently increased the crop yield.

The open drainage network, at present, covers the whole cultivated land in the Nile valley and Delta with a total length of about 16,686 km, of which 67% is in the Delta region and the rest is in Nile Valley (i.e. Upper and Middle Egypt).

## 2.4 Cropping Pattern in Egypt

The cropping pattern used to be dictated by the GoE until 1990. Since then, farmers are free to grow the crops they prefer, which obviously gives rise to allocation challenges on the MoWRI for matching irrigation supply with crops' demand at the distributary canals level. In addition, the characteristics of the system as well as the very limited possibilities to carefully adjust water supplies do not allow "crop-demand-based precision irrigation supply" (Wolters, et al., 2016).

### 2.4.1 Water Requirements and Crops' Pattern

Crops' cultivation takes place during **three** consecutive cropping seasons; the winter, summer and autumn seasons, depending on the irrigation rotation. **Winter** season's crops include wheat, barely, beans and clover (as highlighted in Table 2.1). The crops of the **summer** season are rice, cotton, maize and sugar cane (as illustrated in Table 2.2). Crops of the **autumn** season are similar to summer crops (mainly maize, peanuts, and cotton).

Furthermore, in new lands the irrigation method is either sprinkler or dripper that consumed less water than flood method in old lands. Water productivity indicator in physical unit can be used to compare the productivity of water in old and new lands only for the same crop, as highlighted in Table 2.1 for the winter crops, Table 2.2 for the summer crops.

**Table 2.1:** Crops' water productivity for main **winter** crops in old and new lands under different irrigation methods

| Crop | Wheat | | Long Clover | | Faba bean | | Sugar beet | |
|---|---|---|---|---|---|---|---|---|
| | Old land | New land | Old land | New land | Old land | New land | Old land | New land |
| Irrigation Method | Flood | Sprinkler | Flood | Sprinkler | Flood | Drip | Flood | Drip |
| Water Requirement ($m^3$/feddan) | 1,677 | 1,751 | 2,773 | 2,608 | 1,371 | 1,008 | 2,007 | 1,415 |
| Total Production (Ton/feddan) | 3.41 | 2.48 | 30 | 26 | 1.4 | 1.55 | 25 | 19 |
| Net Return (EGP/feddan) | 5,850 | 3,054 | 1,056 | 950 | 1,000 | 1,732 | 779 | 779 |
| Net Return (USD/feddan)[5] | $1,064 | $555 | $192 | $173 | $182 | $315 | $142 | $142 |
| **Water Productivity Indicators** | | | | | | | | |
| Water Unit Productivity (kg/$m^3$) | 1.97 | 1.37 | 10.82 | 9.97 | 1.02 | 1.54 | 12.46 | 13.43 |
| Water Unit Net Return (EGP/$m^3$) | 3.49 | 1.74 | 0.38 | 0.36 | 0.73 | 1.72 | 0.39 | 0.55 |

Source: Calculated from the survey data of agricultural year 2007/2008 and (CAPMAS, 2004)

5 Average exchange rate for year 2007/2008 was: 1 USD = 5.50 LE (www.oanda.com)

The water productivity is higher in old land than in new lands for both wheat and long clover, while the opposite is the case for faba bean and sugar beet, because of the less water lost in drip method compared with sprinkler and flood and consequently less water consumption.

**Table 2.2:** Crops' water productivity for main **summer** crops in old and new lands under different irrigation methods

| Crop | Maize | | Rice | | Cotton | | Sugarcane | | Onion | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Old land | New land | Old land | New land | Old land | New land | Old land | New land | Old land | New land |
| Irrigation Method | Flood | Drip | Flood | 0 | Flood | 0 | Flood | Drip | Flood | Drip |
| Water Requirement ($m^3$/feddan) | 3,914 | 2,171 | 5,821 | 0 | 3,102 | 0 | 8,854 | 0 | 3,658 | 0 |
| Total Production (Ton/feddan) | 4.37 | 2.85 | 4 | 0 | 1.26 | 0 | 51 | 46 | 15 | 10 |
| Net Return (EGP/feddan) | 734 | 500 | 1,783 | 0 | 2,523 | 0 | 3,998 | 2,700 | 5,898 | 3,796 |
| Net Return (USD/feddan) | $133 | $91 | $324 | $0 | $459 | $0 | $727 | $491 | $1,072 | $690 |
| **Water Productivity Indicators** | | | | | | | | | | |
| Water Unit Productivity (kg/$m^3$) | 1.58 | 1.31 | 0.69 | 0 | 0.41 | 0 | 5.8 | 5.11 | 4.10 | 5.88 |
| Water Unit Net Return (EGP/$m^3$) | 0.25 | 0.23 | 0.31 | 0 | 0.81 | 0 | 0.45 | 0.3 | 1.61 | 2.23 |

Source: Calculated from the survey data of agricultural year 2007/2008 and (CAPMAS, 2004)

As shown in the Table 2.2, there is a high variation in productivity among the different crops. This is attributable to the high response of these crops to water because of the high temperature in summer. In addition, the water productivity is higher in new lands than in old lands for both sugarcane and onion, while rice and cotton are not planted in new lands for technical reasons.

Furthermore, vegetables and fruits are grown all year round, depending on their type, as shown in Table 2.3 and Table 2.4 respectively.

**Table 2.3:** Crops' water productivity for main **vegetable** crops in old and new lands under different irrigation methods

| Crop | Tomato | | Pepper | | Green Peas | |
|---|---|---|---|---|---|---|
| | Old land | New land | Old land | New land | Old land | New land |
| Irrigation Method | Flood | Drip | Flood | 0 | Flood | 0 |
| Water Requirement ($m^3$/feddan) | 2,532 | 2,532 | 2,532 | 2,532 | 2,532 | 2,532 |
| Total Production (Ton/feddan) | 15 | 32 | 6 | 6.7 | 2.8 | 1.86 |
| Net Return EGP/feddan) | 6,383 | 4,615 | 5,433 | 6,000 | 3,500 | 3,291 |
| Net Return (USD/feddan) | $1,161 | $839 | $988 | $1,091 | $636 | $598 |
| **Water Productivity Indicators** | | | | | | |
| Water Unit Productivity (kg/$m^3$) | 5.24 | 14.91 | 2.10 | 2.72 | 0.14 | 0.85 |
| Water Unit Net Return (EGP/$m^3$) | 2.23 | 2.15 | 1.90 | 2.44 | 1.75 | 1.50 |

* Water requirements for vegetables are considered 2,532 $m^3$ because of the absence of accurate data for each crop
Source: Calculated from the survey data of agricultural year 2007/2008 and (CAPMAS, 2004)

The vegetables' production depends mainly on the applied technology, starting with land preparation and until the post-harvest. The productivity of any input (i.e. land, labour, capital and water) depends on the level of the technology applied. It is clear from Table 2.3 that the net return of water unit is less in new lands than in old lands (green peas and tomato) because of their lower net return. This is mainly due to the low price of production due to the increased supply at the time of sale.

**Table 2.4:** Crops' water productivity for main **fruit** crops in old and new lands under different irrigation methods

| Crop | Orange | | Grapes | | Peach | |
|---|---|---|---|---|---|---|
| | Old land | New land | Old land | New land | Old land | New land |
| Irrigation Method | Flood | Drip | Flood | Drip | Flood | Drip |
| Water Requirement ($m^3$/feddan) | 5,280 | 3,500 | 4,400 | 2,800 | 4,000 | 2,800 |
| Total Production (Ton/feddan) | 10 | 8 | 10 | 9 | 4 | 3 |
| Net Return EGP/feddan) | 3,128 | 3,599 | 10,371 | 3,922 | 3,000 | 2,634 |
| Net Return (USD/feddan) | $569 | $654 | $1,886 | $713 | $545 | $479 |
| **Water Productivity Indicators** | | | | | | |
| Water Unit Productivity (kg/$m^3$) | 1.74 | 1.29 | 2.15 | 1.82 | 0.86 | 0.65 |
| Water Unit Net Return (EGP/$m^3$) | 0.54 | 0.62 | 2.22 | 0.79 | 0.64 | 0.66 |

Source: Calculated from the survey data of agricultural year 2007/2008 and (CAPMAS, 2004)

**Note:** Since the above numbers are relatively old (2007 – 2008), the equivalent in dollars was added for the ease of reference, if needed (applied exchange rate for the fiscal year 2007-2008 was 1 USD = EGP 5.50 according to Oanda).

Usually, fruits cultivation activities require huge investments through the whole production process. The water productivity in physical and net return units is lower in new lands compared to old lands for the 3 crops mainly due to the age of trees, the experience of farmers and the ability of finance.

From the previous information, the following remarks are considered important for its impact in supporting the decision making in favour of SWP solutions:

1. The crops' type is very significant, especially for converting to SWP without any kind of financial support.
2. Vegetables and fruits are more suitable crops for SWP system, since the investment costs could be covered in few seasons (shorter payback period).
3. Farmers who are used to cultivate wheat and oily crops need a special support for converting to SWP.
4. Cotton and legumes come at the bottom of the list, since the net return of these crops are relatively very low and cannot support the cost of conversion to SWP system.

In conclusion, it is important to highlight an important fact based on the current practices. Although old lands are characterized by high production value, net revenue, as well as low value of inputs compared to new lands, all these analyses and results would be completely different if water for agriculture purpose was not free of charge.

# Stocktaking of Solar Water Pumping Solutions in Egypt

# 3 Stocktaking of Solar Water Pumping Solutions in Egypt

The SWP solutions interpenetrate different sectors, like agriculture and irrigation, as well as conventional energy sector (diesel in specific), electricity and renewable energy (mainly solar PV energy). Besides, SWP solutions require contributions from both sectors; the public and private, in addition to support from different segments in the economy, starting from landholders and farmers, passing through cooperatives and farmers union, to suppliers and importers, as well as investors, entrepreneurs and financiers.

## 3.1 Main Stakeholder in the Solar Water Pumping Market

There are many stakeholders involved in the solar water pumping market, both on the public and private sectors.

### 3.1.1 The Governmental and Public Stakeholders

Based on their announced mandates, the Ministry of Agriculture and Land Reclamation (MoALR) is responsible for the horizontal expansion of agricultural areas, including the reclamation of new lands, while the Ministry of Water Resources and Irrigation (MoWRI) is responsible for managing all water resources (surface and underground water), as well as the irrigation and drainage networks, throughout the whole country. Since one of the major issues in addressing sustainability in the agriculture sector includes using efficient irrigation systems, therefore close cooperation between these two ministries is essential for the development of the sector.

On the other hand, solar pumping solutions are meant to replace conventional uses of energy, especially the diesel pumps which are widely spread especially in the remote areas. Electricity pumps are also familiar for areas connected to the grid, but not as widely spread as the diesel pumps. Since the management of petroleum and its derivatives lies under the mandate of the Ministry of Petroleum and Mineral Resources (MoPMR) and the management of energy and renewable energy lies under the mandate of the Ministry of Electricity and Renewable Energy (MoERE) together with the New and Renewable Energy Authority (NREA), hence both ministries play an important role with regards to the conversion of pumping systems from the conventional (diesel and electricity) systems to the renewable (SWP) systems.

Accordingly, the MoALR and MoWRI are the main stakeholders for the water and food security, while the MoPMR and MoERE are the main stakeholders for the energy security. The four ministries are therefore the key players in the GoE in relation to setting strategic goals, administrative and legislative framework necessary for boosting implementations, as well as supporting the expansion of applications of SWP solutions.

In addition, the MoWRI is the key stakeholder in charge of the national project for horizontal expansion through increasing an area of 1.5 million feddans in the deserts (underground water) and is also responsible for managing the large pumping stations along the Nile River. Therefore, the MoWRI is the main stakeholder in the GoE as far as the irrigation and water resources is concerned.

### 3.1.2 Private Stakeholders

A number of small companies are operating actively on the supply side of the local SWP market, offering SWP systems and solutions with various imported models and brands from different manufacturers, in addition to offering installation and maintenance services through local workforce (mainly technicians).

The list presented in Table 3.1 shows the different technical components (inverters, PV and pumps) and examples of their respective suppliers in the local market.

**Table 3.1:** List of different SWP system components available in Egypt and examples of their suppliers

| Item | Inverters / Controllers | | Solar PV Panels | | Water Pumps | |
|---|---|---|---|---|---|---|
| | Supplier | Manufacturer | Supplier | Manufacturer | Supplier | Manufacturer |
| 1 | Invt | China | SUNTECH | China | Shakti | India |
| 2 | POWTRAN | China | GTS – CNBM | China | Speroni | Italy |
| 3 | ABB | Switzerland | Fortune CP | Japan | LORENTZ | German |
| 4 | VEICHI | China | Trina Solar | China | KPS | Turkey |
| 5 | Kostal | German | ReneSola | China | Varuna | India |
| 6 | Effekta | German | JINKO Solar | China | Grundfos | Denmark |
| 7 | Socomec | France | ALEO | German | Alfa Laval | Sweden |
| 8 | MW Mean Well | Taiwan | EMMVEE | India | Franklin Electric | United State |
| 9 | Huawei | China | AxSun Solar | German | ALLWEILER-FARID | German |
| 10 | Ingeteam | Spain | Resun Solar | China | Farrouk and Awad | N.D |
| 11 | Schneider Electric | France | CSG PVTeck | China | Bharat | India |
| 12 | Danfoss | Denmark | PTP Energy Solutions | China | Ahmed Daoud | Egypt |
| 13 | Growatt | China | SUNTECH | China | Calpeda | Italy |
| 14 | - | - | - | - | KSB | Germany |
| 15 | - | - | - | - | Shakti | India |

Usually, the SWP system has an average lifetime of 15 to 20 years for the solar panel and around seven years for the invertor or controller, and requires replacement of wearing parts through its operational lifetime. Since these SWP systems rely mainly on solar power, there will be minimal economic burden on farmers compared to the conventional pumps (diesel fuel and power costs). At the same time, SWP systems contribute to the environmental protection with no carbon emissions and no accompanying pollution.

### 3.1.3 Landholders and Famers

This category reflects the demand side of the local market for SWP solutions and therefore is also a very important target group for the expansion of the SWP market. Due to the fragmentation of the cultivated areas, the farmers unions, cooperatives and farmers associations should be consolidated also under this category, for their important role as key players in the market.

### 3.1.4 Financial Institutions and Investors

As financiers, the financial institutions (local banks and international donors) are very important stakeholders pouring and directing investments (local and foreign) in the market. Their role is therefore essential and rather crucial for the development and expansion of SWP market. (More details will be discussed in section 3.4).

### 3.1.5 Stakeholders in the Industry Sector

Most of the RE components and systems are imported form international manufacturers. However, there are some entities with remarkable contributions in the local market, especially for manufacturing and assembly of solar PV panels. The Arab Renewable Energy Company (ARECO), which is affiliated to Arab Organization for Industrialization (AOI), has an important role in supplying and installing solar PV panels required to operate the government wells using RE applications (more about it in section 6.2). In addition, there are several factories operating in the production and assembly of solar PV panels in Egypt, e.g. Benha Electronics, ARE Group, Power Field, Sun-Prism factories and others.

## 3.2 Types of Available Water Pump Solutions

Apart from the source of power used to operate the water pump (electricity, diesel, or solar PV); there are 2 types of water pumps (Sontake & Kalamkar, 2016):

1. **Surface mounted Pumps:** It is used to transfer water from the surface of canals or ground storage tanks to the fields for irrigation or to smaller canals and water outlets or also to storage tanks as in Figure 3.1. These pumps can be easily affected by harsh weather.

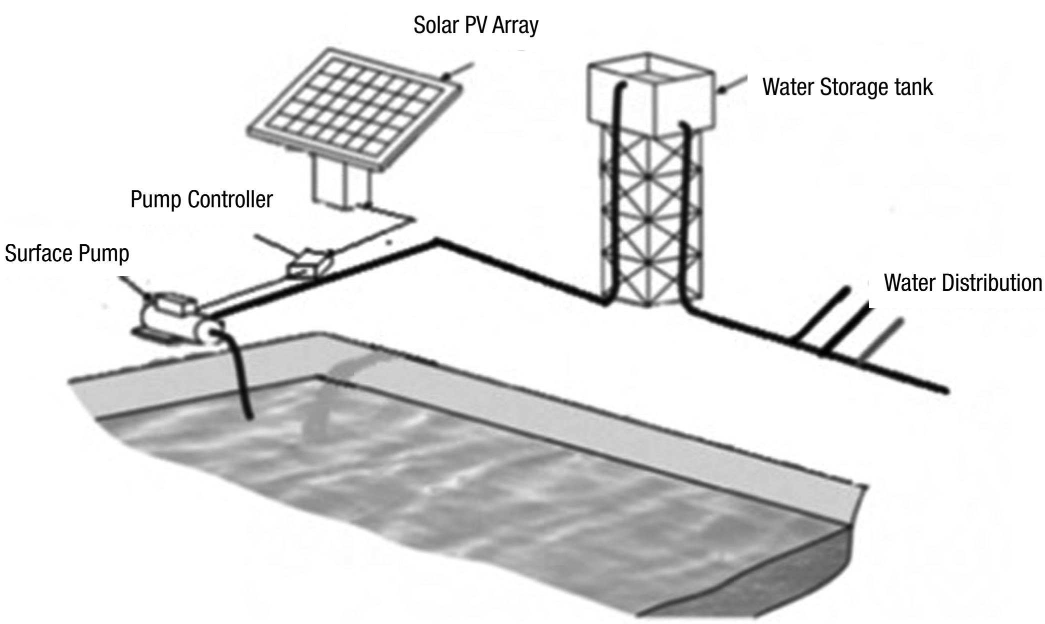


**Figure 3.1:** Layout of SWP with surface mounted pump (Sontake & Kalamkar, 2016)

2. **Submersible Pumps:** It is used to abstract and push water from deep underground wells to irrigate the fields directly or to store water in storage tanks (for night irrigation). This pump will not work until submerged completely in water.

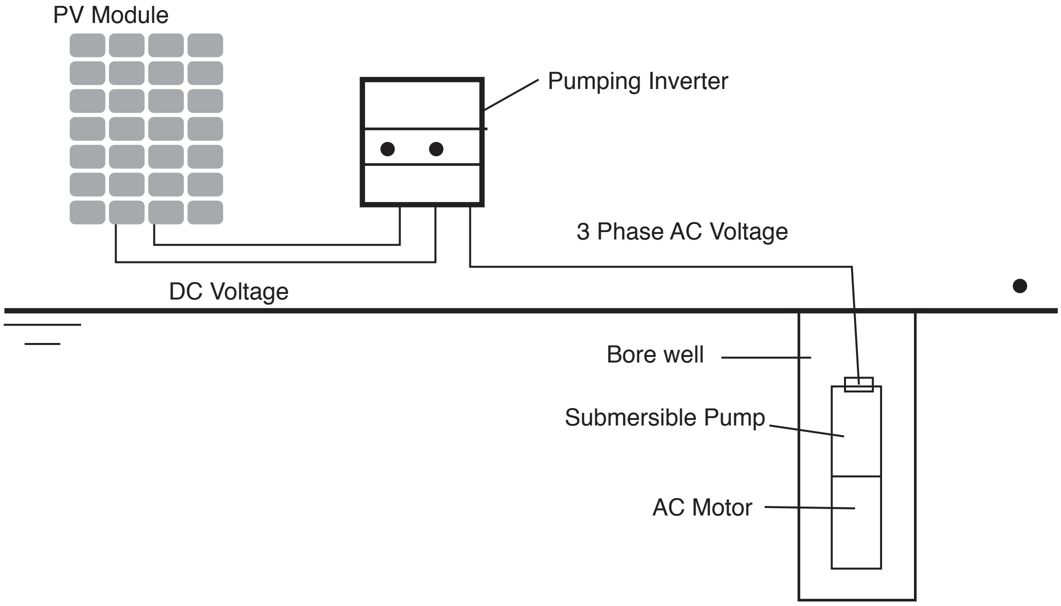


**Figure 3.2:** Layout of SWP with submersible pump (Sontake & Kalamkar, 2016)

The current shares of these pumps in the Egyptian market were portrayed earlier in section 2.3.1.

## 3.3 Technical Design of Solar Water Pumping Systems

Many designs are available for different applications in the market. At least nine of the common SWP systems designs were discussed in an informative publication for GIZ under the name *"Solar Pumping Systems in Egypt – Practical Guide for Self-Assessment"*, from which the following summary is extracted:

a. **Stand-alone system for direct irrigation:** This is the simplest form, where the pump is directly connected to the inverter and it starts to operate as long as the power from the solar panels keeps the pump running. This system can also be connected to batteries to prolong the operations time, especially that the batteries can store energy in the early morning and before sunset that is not sufficient for the pump to run.

b. **Stand-alone system with storage tanks:** There are two common designs for storage tanks:

   1. **High-level storage tanks:** This system is connected to a high-level storage tank, to which water is pumped during the whole day and water is then released for irrigation when needed, based on the constant pressure of gravity.

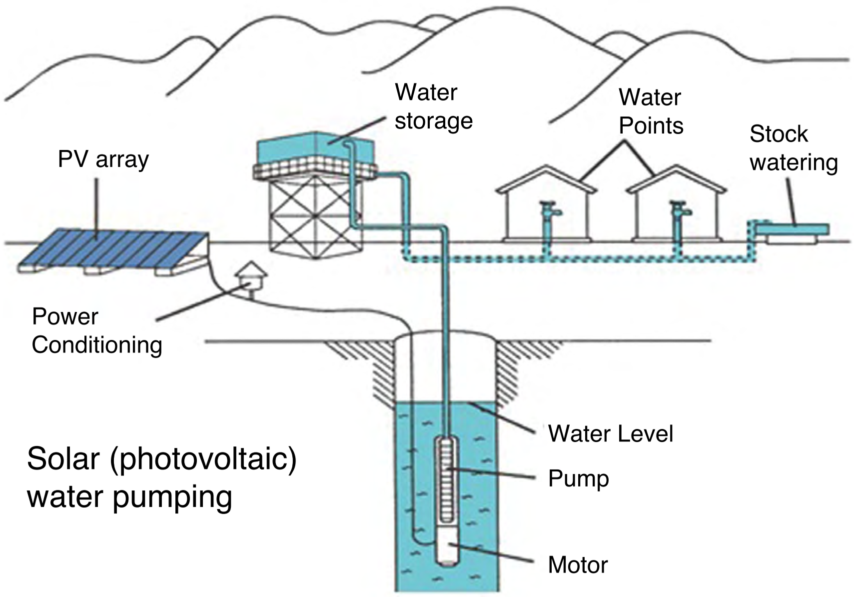


**Figure 3.3:** Schematic of a SWP system with high-level storage tank

**2. Ground level storage tanks:**
This system is connected to a ground level reservoir the full day, and then extracted from the tank using a booster pump which also operates by the solar power. This system is more efficient and less expensive compared to the use of batteries (under point a).

Both systems with storage tanks are specially known for their flexibility and suitability for any irrigation profile (day and night).

**c. Hybrid systems (solar and diesel):**

There are four types of available solar-diesel hybrid systems:

1. Hybrid system with switch operation (and high-level storage tank)
2. Hybrid system with batteries
3. Hybrid systems with ground level storage tank and booster pump
4. Hybrid systems with fuel saver

These systems allow using conventional diesel generators together with SWP systems (i.e. rely on the solar PV during the sunrise and on diesel in the evenings and for backup).

For the sake of this study, more details the components the relevant SWP systems only will be highlighted, as explained in points a and b[6].

[6] In case the reader is interested in more technical details on these systems, it is recommended to refer to the publication "Solar Pump Systems in Egypt: Practical Guidelines for Self-Assessment". The manual is available through this link: http://www.aschoff-solar.com/index_htm_files/Solar%20Guidelines.pdf

### 3.3.1 Main Components of Solar Water Pumping Systems

The SWP systems are composed of three main technical components: solar PV panels, inverters and pumps as shown in Figure 3.4. In addition, for its proper operations, these SWP systems require support structure and foundation, tracking mechanism, electrical interconnection cables, grounding-kit, plumping pipes and storage tanks to store the excess water.

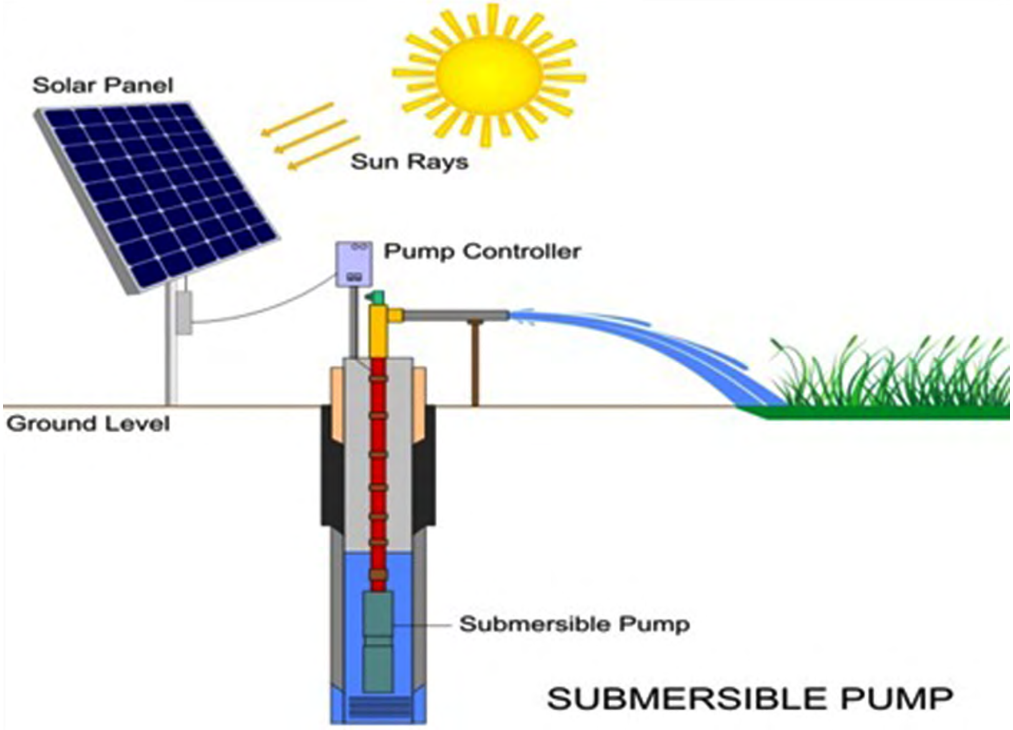


**Figure 3.4:** Main components of SWP system (underground water, direct irrigation without storage tank)

For a better understanding about the main components of SWP systems, here are more details:

1. **Solar panels or modules:**
   Solar panels (array) are the main components used for powering the SWPs. Several solar panels connected together in arrays produce DC power, interconnections are made using series or parallel combinations to achieve the desired voltage and power for the pump. The expected lifetime of the high quality solar PV panels is 20 to 25 years.

2. **AC Inverter or DC Controller:**
   Inverters (for AC) or controllers (for DC) are an important part of any solar PV installation; they are the brains of the system (Figure 3.5). As a power conditioner, its main job is to convert DC power produced by the solar array into usable AC power to run the electric drive of the water pump. Controllers and inverters can also provide diagnostic information to help operation and maintenance (O&M) crews identify and fix system issues (if any). The inverter's lifetime is expected to be around to five to seven years.

**Figure 3.5:** Solar panels with DC controller or inverter

3. **Water pump:**

   For underground water, centrifugal or submersible pumps (for underground water) are connected directly to the solar array and operate using DC power produced by the solar array. Water pumps are available in several capacities, depending upon the requirement of water. The water flow (output) depends on both, the power of the pump and the depth of the well. As for surface water, surface lifting pump is needed to pump water directly from canals to the fields.

   The water pump always comes as a set of two components, the rotor and the electric drive as illustrated in Figure 3.6. Under the optimum operational conditions, the average lifetime of the water pump-set is expected to be seven years and the replacement cost is around 30% of the total cost of the system.

The pump rotor

The electric drive

**Figure 3.6:** Components of the water pump

4. Optional components:

   a. **Storage tanks (or reservoirs):**
   Ground storage tanks or high-level storage tanks are required to store water to be used when needed, especially useful for night irrigation and during cloudy days. An example of the ground and high-level storage units is depicted in Figure 3.7 A and B respectively.

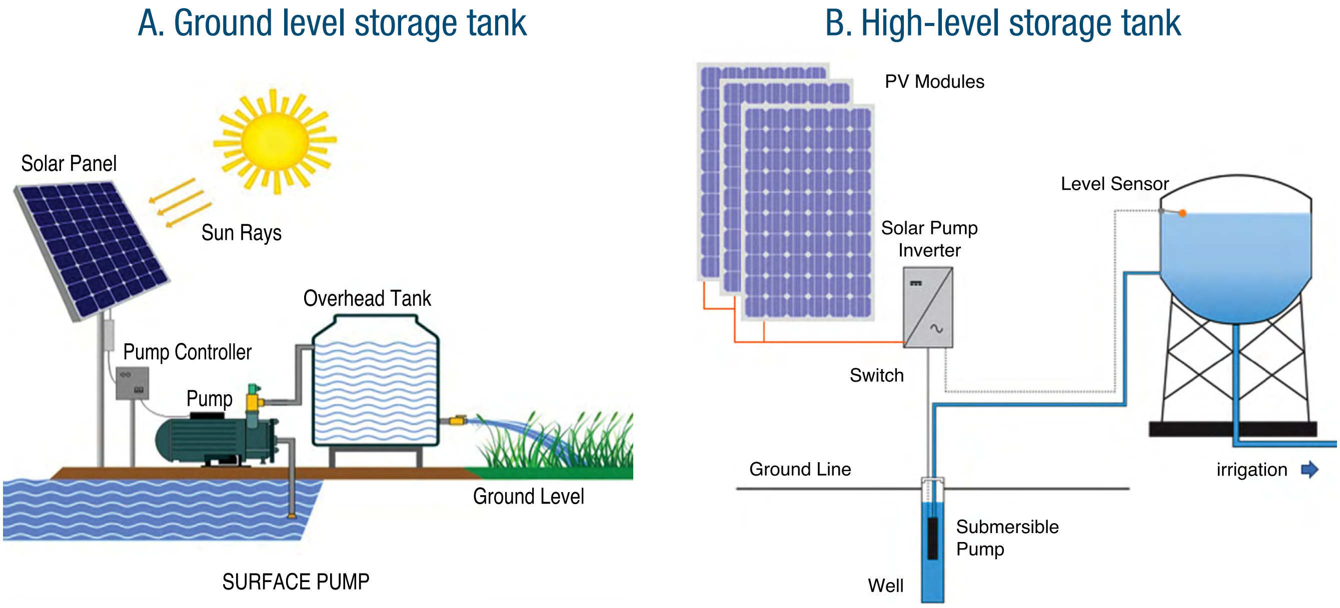


**Figure 3.7:** Ground and high-level storage tanks for SWP system (surface water and underground water, with storage tank)

Storage tanks have many advantages and introduce flexibility to the irrigation system, like possibility for night irrigation or irrigation during cloudy days, and in case of emergency. In addition, the ground tanks can be used to grow fish, which is an additional source of income and the fish wastes serve further as a natural fertilizer for the plants and hence increasing productivity. The main disadvantage is the extra initial cost; however, the size of the storage tank can be optimized to minimize the cost. The storage of two to five days of water is sufficient (Sontake & Kalamkar, 2016). Besides, another pump (smaller size, running with diesel genset) might be needed for the night irrigation. However, this pump is also useful to control the flow and pressure of the dripping network (an additional advantage).

   b. **Batteries:**
   Batteries are used to store the excess solar energy in form of DC electrical energy to be used in water pumping during the absence of the sun. The main challenges for using batteries are (1) the depth of discharge (for underground water) and that (2) batteries need cooling to be more efficient. Moreover, the average lifetime of batteries depends on the number of cycles (charge and discharge). These factors together with its extra cost make the use of batteries less preferable.

   c. **Monitoring system:**
   This component is important to monitor the output and is useful especially for remote installations, but it is optional.

In addition to these components, the installation of SWP system also requires:

1. **Mounting structure and foundations:**
   The mounting structure (usually metallic) provides stability and support to the mounted solar PV array and protects it from theft or natural calamities (wind speed). There are different types of mounting structure; it could be fixed, single axis tracker, or dual axis tracker as shown in Figure 3.8, Figure 3.9 and Figure 3.10 respectively. Foundations are required for both, the solar array and the pump.

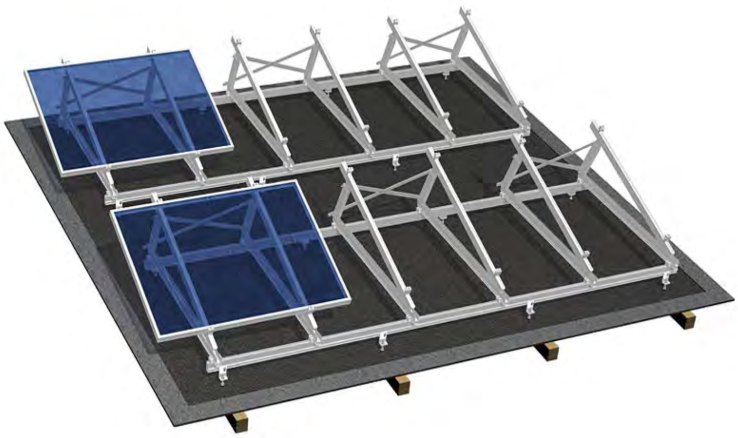

**Figure 3.8:** Fixed structure for solar PV array

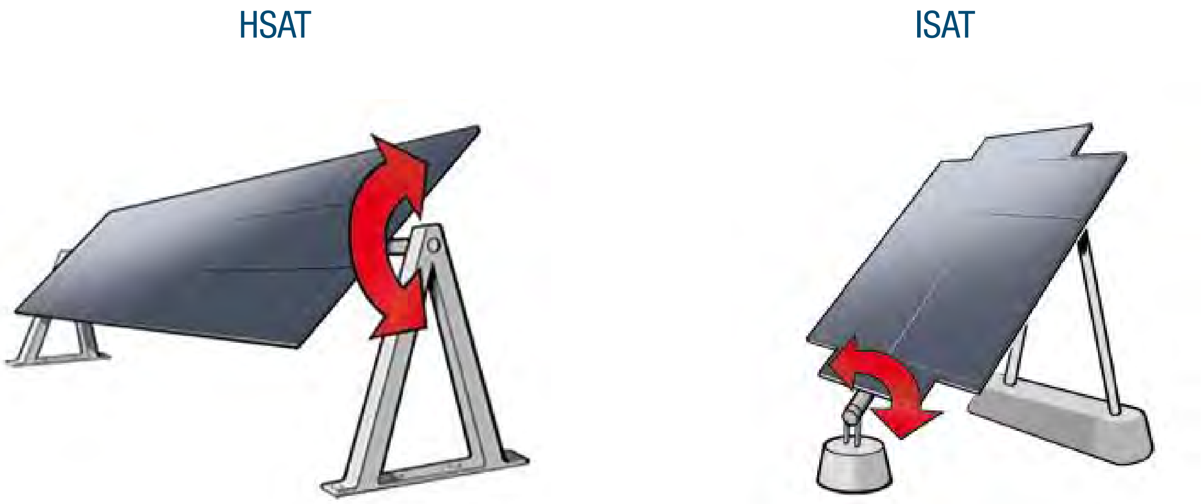


**Figure 3.9:** Horizontal and Inclined Single Axis Tracker (HSAT and ISAT) for solar PV array

Vertical Axis rotating structure

Dual Axis Tracker (DAT)

**Figure 3.10:** Vertical Axis rotating structure and Dual Axis Tracker (DAT)

2. **Tracking mechanism:**
   To maximize the output of water, either automatic or manual tracking device can be fixed to the support structure, which increases the output of water by adjusting the direction of the solar array to face the sun as it moves across the sky. The tracking device could increase the water output by around 25% to 30% (or even up to 50% (Sontake & Kalamkar, 2016), which justifies the increase in the accompanying extra cost of around 5% to 10% (automatic tracking is more expensive than manual tracking) and needs maintenance.

3. **Electrical interconnections:**
   A set of cables of appropriate size, junction boxes, connectors and switches are required along with the installation (DC and AC cables, conduits, MC4, fuses, circuit breakers, etc.)

4. **Grounding kit:**
   This kit is important as a safety measure, especially in case of lightning or short circuit.

5. **Plumbing:**
   This is an important part of the installation, including the pipes and irrigation network fittings required to connect the pump to the storage tank and/or to the irrigation field.

Most of the components required for installation are manufactured locally and hence could be considered for further development in the local value chain and job creation.

## 3.4 Financial Solutions and Incentives

Availability of finance has always played a key role in promoting markets and technologies. The GoE has been investing huge funds for the development of the agriculture and irrigation sectors in cooperation with developing organizations, and has adopted an integrated water management practices in different regions and governorates in the country.

However, despite the importance of the applications of SWP in serving the Water-Energy-Food nexus and in supporting different sustainable development goals, the financial solutions currently available in the market are considered limited, where the undesirable financing solutions have been the main barriers to investing in SWP systems.

### 3.4.1 Governmental Initiative

#### 3.4.1.1. Ministry of Agriculture and Land Reclamation

In May 2017, the MoALR announced a new project "SASME"[7] in cooperation with the French Development Agency (AFD) and the European Union (EU). The relevant components of this project are to (1) enhance access to finance for rural SMEs through creation of (i) a dedicated credit fund for SMEs via the ministry's Agriculture Development Program to be managed by an agent bank, (ii) a risk sharing mechanism to increase outreach to small farmers (without or with only limited collateral) as well as large projects (based on a business plan approach), and (2) provide technical assistance to key stakeholders in the lending and guarantee granting process, including financial and non-financial intermediaries, agriculture SMEs, service providers and business development.

Not many details are announced at this stage, but the initiative seems to satisfy an existing need especially for small farmers, who are typically failing to satisfy the bank collateral requirements and hence are disqualified for being "non-bankable clients".

#### 3.4.1.2. Ministry of Water Resources and Irrigation

The MoWRI (Underground Water Sector) is the key stakeholder in charge of the national program to reclaim 1.5 million feddans. According to media announcements, 25% of the government wells will be operated using renewable energy applications.

Therefore, the MoWRI is adopting an initiative to "lead by example", where all the government wells operating off-grid[8] in the western deserts using diesel and/or hybrid systems will be converted to solar PV systems, in order to serve the existing agriculture communities in this area. In specific, 600 governmental wells will operate using solar PV systems by 2022. This initiative has been in action already and the GoE will be pouring "easy funds" for this purpose.

In Dakhla oasis, a total of 52 wells are considered, of which 25 or 26 are done and currently running on solar PV systems. The diameter of each well is 33 cm (~13 inch), with one pump of capacity 30 kW installed at depth of 40 m (~6 inch in size), while the installed capacity of solar PV is 65 kW. The average time for operating these wells is from sunrise to sunset (~8 hours daily); the average withdrawal is 200 $m^3$ per hour, with a safe pumping rate up to 1,600 $m^3$ per day to maintain the sustainability of these wells. The common corps cultivated using the underground water from these wells are: wheat, dates and alfalfa.

Following the same pattern, the implementation of eight more wells is currently ongoing in Albahareya Oasis. The average cost per well is around EGP 8 to 16 million (~USD 0.5 to 1 million for each well)[9].

7 http://www.afci.de/jobs/support-agriculture-smes-sasme and http://www.afci.de/node/20

8 Off-grid refers to areas that are not connected to the national electricity, which provides electricity to most of the country.

9 The Egyptian currency devaluation resulted in almost doubling the cost.

### 3.4.2 Financial and Operational Leasing

**The Agriculture Bank of Egypt (ABE):**

The bank was previously known as Agriculture Development and Credit Bank and it has been undergoing a reform process since 2016 to improve its service. For ages, the ABE has been a key public financial institute for farmers and farmers associations in supporting the agriculture activities and process. Based on law 84/2016, the legal structure of the bank was changed and it is expected that it will assume more responsibility to offer innovative financial solutions supporting the development of the agriculture sector, farmers and rural areas, in order to cope with the market requirements reaching for food security and sufficiency (ABE, 2017).

The ABE offers financial loans to farmers with interest rate around 5%. However, since ABE is working under the umbrella and control of the Central Bank of Egypt, the loan requirements and eligibility criteria (especially collaterals) will remain a critical issue for farmers' bankability (from banks' perspective) and accessibility to loans (from farmers perspective).

**Leasing as a Financial Mechanism**:

Leasing has proved to be a reliable and cash-flow friendly financing tool, especially for the purchase of equipment and machines (assets) to be used for different activities. Based on a leasing agreement, the right to use a specific asset owned by the lessor (one party) is transferred to the lessee (other party) according to a contract concluded between the two parties, and entitling the lessee to use the asset (owned by the lessor) against the payment of periodic instalments over a specific timespan. At the end of the agreed period, the lessee may purchase the asset from the lessor or return it.

Among the main advantage of leasing are: (1) reducing the upfront cash outflow and spreading the payments over several years, (2) owning the asset is not obligatory, (3) ease of replacement and upgrading with modern technology at the end of the leasing term, (4) flexibility of payments, since the instalments' schedule is tailored to suit the lessee cash flow cycle, which accordingly satisfy existing needs in the Egyptian market (especially for small farmers), (5) less complicated administrative process and requirements compared to bank loans, (6) once agreed, the terms of the contract remain fixed for the entire duration, therefore protecting the lessee from rising financial costs or changing interest rates.

Many leasing companies are operating now in Egypt, all operating under supervision of the Egyptian Financial Supervisory Authority (EFSA)[10], which is in charge of regulating the non-banking financial markets and instruments. EFSA is also the administrative authority for companies established under the provision of the financial leasing law 95/1995. In addition, few of the leasing companies currently operating in the market are also affiliated to Commercial banks.

A successful example of applying the leasing tool in SWP applications is the cooperation between the Egyptian PV Company "KarmSolar" and EFG Hermes Leasing, where the latter is currently providing financing solutions for all the solutions offered by KarmSolar, with favourable conditions[11] to satisfy the market needs. The total of this agreement is EGP 10 million, with 6% interest rate for five years and six months grace period.

### 3.4.3 Development and Green Funds

**Green Economy Financing Facility Egypt:**

Green Economy Financing Facility (GEFF) is a product of the European Bank of Reconstruction and Development (EBRD), in cooperation with the Agence Française de Développement (AFD) and the European Investment Bank (EIB) and is financially supported by the Neighbourhood Investment Facility of the European Union and the EBRD Shareholder Special Fund with the aim of promoting the green economy.

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10 EFSA: http://www.efsa.gov.eg/content/efsa_en/lease_pages_en/main_lease_page_en.htm

11 More information through: http://karmsolar.com/leasing/

GEFF is operating through participating financial institutions in Egypt (currently QNB Al Ahly and NBK Egypt) and provides finance and advice for private sector businesses to improve competitiveness through high performance technology and practices. It offers a package of three main activities: (1) technical support to develop green investment projects, (2) finance to implement these projects, and (3) grant support for successful completion (based on project's savings).

The technical support is provided by the local team for various stages of project, starting from projects' inception, going through investment appraisal and until project implementations. This helps identifying the best solutions and ensuring quality green community are successfully financed (hence best value of money). A loan applicant is considered primarily eligible for GEFF loans if (1) it is for an individual or existing private legal entity registered in Egypt and generated profits for 2 years, and (2) the loan is to be used for investments in Egypt. Among the different types of beneficiaries, the following four types are relevant with respect to SWP installations: (1) individuals or businesses that undertake eligible projects on their own behalf, (2) service providers implementing eligible projects on behalf of any individual or entity that satisfies the criteria for an eligible beneficiary (according to on-lending agreements with banks), (3) vendors of equipment, and (4) Energy Service Companies (ESCos) providing third-party financing which is still limited in Egypt.

The maximum amount of loan ranges from USD 300,000 and up to USD five million[12] , which together with other conditions depend on the type of beneficiary and the project to be financed. As an investment incentive, all types of loans (except service providers' and vendors' loans) are eligible for grant support equivalent to 10% or 15% of the eligible costs based on the project's savings and upon successful completion and verification of projects.

Since GEFF Egypt is operating through local banks, the loan conditions and eligibility criteria are determined according to their internal regulations. For landholders and farmers, the provision of legal proof of land possession remains the major challenge among the list of requirements, since failure to submit a legal proof of land ownership and possession was the primary reason for disqualifying many loan applications. Another barrier is the bankability of the borrowers in some cases.

Based on its success stories, GEFF terms proved to be suitable for financing SWP in Egypt, since replacing diesel pumps with SWP is found bankable, with no fuel supply risk and low maintenance expenses. In general, the payback period (PBP) is less than five years and internal rate of return (IRR) of around 18% to 20% makes the SWP an interesting investment.

**Case study of GEFFEgypt:**

**Application: Farm irrigation**

Investment cost: USD 100,000
Implementation period: 1 month
Energy saving: 110 MWh/year
Economic saving: USD 30,000
Simple payback period: 3.3 years
CO2 Reduction: 70 Ton $CO_2$ eq/Year
NPV: USD 104,326
PBP: 4.5 years
IRR: 29.4%

**Remarks:** A 70 KVA diesel generator driving a pump in a farm is replaced by a solar water pumping system. Fuel price, including transport, used is EGP 2 per litre of diesel oil, discount rate 12%

12 The full eligibility criteria, terms and conditions are available through: www.ebrdgeff.com/egypt

## 3.4.4 Subsidized Loans

### 3.4.4.1. Micro, Small and Medium Enterprise Development Agency (MSM-EDA)

Before April 2017, its official name was the Social Fund for Development (SFD). It was established in 1991 to provide support to improve the living conditions, through increasing access to improved financial and non-financial services for the Micro, Small and Medium Enterprises (MSMEs) for the sake of human and community development.

MSM-EDA is operating in five main sectors; industry, service, commercial, professional and agriculture, each with a set of services. The eligibility criteria for the different loans apply for different kind of beneficiaries.

In the agriculture sector, it provides three suitable lending services: (1) **direct loans** from a minimum of EGP 30,000 up to EGP one million (micro loan), with flat interest rate up to 6% (flat), as well as reasonable loans to **MSMEs** (suppliers) for amounts more than EGP 10 million.

The (2) **suppliers' loans** have reasonable conditions: simple interest rate of 6%, with grace period between 6 and 12 months and maturity up to 7 years (maximum), without banking fees. These conditions are more favourable compared to the loans from the Central Bank of Egypt (CBE), with maturity only five years, maximum grace period of six months, and banking and administrative fees apply. The two main selection criteria for supporting companies are: (1) paid capital in the commercial register should not exceed EGP one million*, (2) number of employees the socially insured employees should not exceed 50 employees*. These loans might be suitable for companies operating in SWP installations and maintenance.

*(*) these limits are expected to be changed in the future.*

Furthermore, MSM-EDA provides funds as (3) **intermediary loans** (for agencies acting as aggregator), provided that these intermediaries have experience with granting loans and financial facilities (on-lending track record) and it is stated among its main legal activities, financial credibility and reliable administrative structure. The **intermediary loans** are provided with an interest rate of 8.5% (decreasing rate) and on-lending rate to beneficiaries of 11% and for a maximum period of seven years with grace period of six months. In this case, the intermediary agencies take over the risk of loan repayment.

The presentation of a legal prove of land possession is an important prerequisite in the application process for the direct and suppliers' loans. The private (direct) loans are considered to be convenient for landholders and farmers possessing big areas between 5 and 10 feddans, especially that the smaller areas (<5 feddans) are in some cases considered to be not commercial enough from MSM-EDA's perspective[13] . In addition, the cooperatives or farmers associations can benefit and use for supporting small farmers to install SWP through the intermediary loans, especially if they could prove their financial credibility and satisfy the eligibility criteria. Therefore, through this loan a considerable percentage of micro and small farmers could have access to finance to support the transformation to SWP instead of diesel or electric water pumps.

In addition to the variable financial services, MSM-EDA offers a wide range of non-financial services to support SMEs including entrepreneurial training, marketing, business incubation, feasibility studies, technical assistance and others. The suppliers operating in the SWP market can benefit from these services to promote their business and contribute to community development.

[13] Meeting with MSM-EDA's high level official (Dr Walid Darwish, June 2017)

# Main Opportunities and Challenges for Solar Pumping in Egypt

# 4 Main Opportunities and Challenges for Solar Pumping in Egypt

Renewable Energy technologies have received a good share of innovation and enhancements especially in systems' design, which was reflected in improvements in efficiency, reliability and longevity. SWP solutions are being installed in different areas along the country over the last few years and have proven record of reliability, especially for its minimal operation and maintenance costs.

Recent studies were published, showing that SWP in Egypt is economically more feasible than the diesel engine pumping systems (Shouman, et al., 2016). Nowadays, with the various announced strategies, especially that for the new national project for reclamation of three million feddans in remote areas, the potential of SWP systems' implementation is considerably increasing.

## 4.1 Main Advantages and Limitations of SWP systems

Before exploring the market opportunities and challenges, it is good to understand and summarize the main advantages and limitations of the SWP systems (ENID, 2013):

### 4.1.1 Advantages of SWP Systems

1. **Low operating cost:**
   Compared to other pumps using conventional energy sources (diesel or electricity), the operating cost is minimal, as long as the sunshine is available during the daytime.

2. **Low maintenance cost:**
   A well-designed SWP system requires minimal technical maintenance (annually) and regular cleaning of the installed solar panels (once a week).

3. **Flexibility of land use:**
   The array of solar panels need not be installed right beside the underground water well, but rather it can be installed anywhere up to 20 meters away from it. Further distances can be also accommodated, provided that wheeling green solar electricity through the national or local electricity network is permitted.

4. **Reliability and efficiency:**
   The SWP systems can be used for many long hours as needed during the daytime and can also be turned on and off as required, provided that the period between two operations is more than 30 seconds. The SWP systems give the maximum water output during summer dry months where high solar irradiance is available, i.e. when the SWP is mostly needed.

5. **Environmental friendly and safety:**
   In addition to being in harmony with nature with no carbon emissions associated with its operations, it is safe for human and other living beings (cattle, animals, etc) since there is limited chance for any hazards due to wiring connections.

6. Flexibility and ease of operations:
   The SWP systems could be monitored and controlled through internet or GPRS, and can run on automatic or manual mode.

7. **More profitable:**
   A well designed SWP system has a reasonable payback period, where unstable energy prices, high inflation rates and shortage of supply do not exist. For serious investors, the older the SWP system gets, the lower the cost of energy. In other words, on using SWP over long period of time, its higher capital cost is more effectively used.

### 4.1.2 Limitations of SWP Systems

1. **Relatively low water supply:**
   The water supply (yield) depends mainly on the capacity of the installed SWPs. The SWPs of lower capacity are relatively cheaper in price, and their yield (water supply) is accordingly low. Low capacity SWPs are therefore not suitable where the requirement for water is very high.

2. **Fluctuating water output:**
   This is one of the limiting factors for SWPs, that it might not satisfy the increased water demand. Since it is highly dependent on the sunlight, the output varies from the highest around noon and least in the early morning and evening. However, economical solutions (like storage tanks) are offered for this limitation.

3. **The risk of theft:**
   The solar panels can be stolen in some areas. This requires precautionary measures from the farmers. Ideally, the solar array could be installed on rooftops or be surrounded by siege.

## 4.2 Market Opportunities and Drivers

The market price of solar PV technology is now decreasing due to the economies of scale. This has been reflected in launching different programs to accelerate the deployment of solar PV applications. The off-grid installed capacity was reported to be 30 MW by the Electricity Distribution Company (March 2017). Also private investments increased to reach USD 805 million in Egypt (BNEF, 2017).

### 4.2.1 Announced National Strategies

The GoE has clear strategic goals to increase the share of RE installations in the energy mix. With regards to the electricity generation, the MoERE announced the planned share of RE to reach 20% by 2022 and 37% by 2035 (NREA, 2017).

Since 2015 the GoE has started an action plan to uplift subsidies from all fuel energy (including diesel) and electricity. In addition to the recent devaluation of the Egyptian Pound against foreign currencies, the diesel prices will continue to increase, if diesel is available in the first place. This continuous increase will increase the competitive advantage of SWP in the near future and at the long run.

Furthermore, in an attempt to encourage implementation of RE projects, the GoE exempted all the RE systems and equipment from the customs and import charges and only 2% (flat rate) applies to the imported systems, provided that a written confirmation from NREA is present the customs clearance authority. Therefore, this applies also to the solar PV solutions used for irrigation purposes.

With regards to the water strategy 2030, the MoWRI is undertaking certain measures to ensure more efficient use and sustainability of water resources and minimize the possibility of violation actions for surface and underground water. Part of these measures is in collaboration with the MoALR with the aim of rationalizing use of irrigation water. This introduces control measures like reducing the areas used for cultivated crops that require excessive amounts water (like rice and sugarcane) and replacing it with other water efficient crops (like sugar beet). Other measures include updating the laws governing wells and underground water to prevent violation due to unauthorized digging of wells and exceeding allowed rates for wells discharging.

### 4.2.2 National Project for Horizontal Expansion

Since the announcement of the national project to expand the agriculture and cultivated area through reclamation of 3 million feddans in 3 phases, the MoWRI has executed pilot projects in the assigned locations using SWP in extracting the irrigation water from the wells (see 3.4.1.2).

This project is designed carefully by the GoE represented by the MoWRI, with the purpose of land reclamation and cultivation, to increase the agriculture area and contribute to food security. In addition, the project offers employment opportunities especially for graduated youth and small farmers. The project is implemented by the Egyptian Countryside Development Company, with close collaboration and cooperation with the MoWRI.

The land is allocated in the form of shares in joint stock companies. The price per share is determined inclusive of the value of basic infrastructure, utilities and facilities implemented by the GoE. The number of instalments and duration of payments are determined also by the GoE, depending on the form of land allocation.

In all cases, to avoid one of the main challenges of the agriculture area due to fragmentations along the Nile valley, the assigned locations are divided into blocks of 238 feddans as Shareholding Company, each block is supported by a water well for irrigation purposes and its ownership could be shared by a minimum of 10 and maximum of 23 owners.

The allocated areas are available in different forms:

1. **Usufruct for 49 years:** designed for Arab and foreign companies:
    a. Small areas: a minimum of five feddans per individual and up to 10,000 feddans.
    b. Large areas: between 10,000 and 50,000 feddans, a grace period of 3 years is granted to investors under this category.
2. **Usufruct for the purpose of acquisition:** designed for companies and associations, with priority to those companies that present comprehensive agricultural and industrial projects; and imposes the condition of Egyptian contribution by 100% for development purposes. Land is offered for acquisition in pieces (between 1,000 and 10,000 feddans).

The property title shall be granted to the company only after the completing the cultivation of the entire area and payment of all due instalments to the government according to the agreed schedule.

Media reports indicated that the MoWRI conducted an indispensable study to ensure the availability of irrigation water required for the proposed locations for the whole national project, as displayed in Figure 4.1.

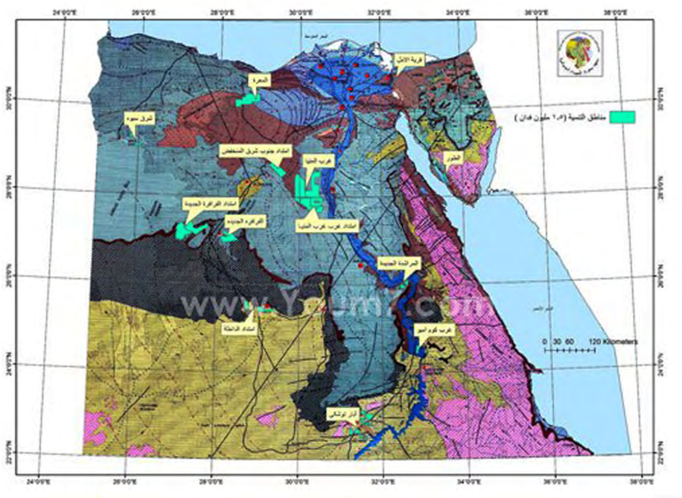

**Figure 4.1:** Preliminary locations for the implementation of the national project to reclaim 1.5 million feddans

(Source: Youm7 Newspaper, http://www.youm7.com/)

The first phase of the national project is expected to include an agriculture and cultivation area of around 876,000 feddans, depending mainly on underground water for irrigation as shown in Table 4.1

**Table 4.1:** List of different SWP system components available in Egypt and examples of their suppliers

| Location | Agriculture Area (1000 Feddan) | Number of Wells | Well Depth (m) |
|---|---|---|---|
| Toshka | 10 | 100 | 250 |
| Moghra | 150 | 1,352 | 200 |
| Old Farafra | 92 | 480 | 1,000 |
| New Farafra | 20 | 100 | 1,000 |
| East Owinat | 100 | 800 | 400 |
| West Menia | 420 | 1,450 | 1,000 |
| South Qattara | 50 | 220 | 1,200 |
| Siwa | 30 | 120 | 1,200 |
| Total | 872 | 4,622 | |

(Source: ECRI)

Based on insights from the MoWRI, a total of 1,000 wells are currently either done or under implementation. In Toskha, 50 wells have been prepared in cooperation with the National Organization for Military Production (NOMP), applying integrated systems including: solar PV panel, smart pumps, surface storage tanks (capacity 2,000 $m^3$) and cameras (for monitoring). The purpose of smart pumps is to be operated remotely, while eliminating the human intervention between the MoWRI and the wells' users. The diameter of these wells is also 33 cm (~13 inches), in each well a pump is installed with capacity of 37 kW (five inches) at around 90 m depth (dynamic water level), to yield from 800 to 1,000 $m^3$ per day (safe pumping rate), and installed capacity of solar PV is 60 kW for each well. The average cost of each well was around EGP 1.3 million (~ USD 150,000 based on the announced exchange rates in 2016). The average cost of running each well is expected to be around EGP 480,000 per year[14] . The common cultivated crops in Toshka are wheat, mango and dates.

In general, the wells for this project are designed to serve an area of 230 feddans and will be located at least one kilometer away from the farms, which shall occupy 70% (minimum) of this area to be used for agriculture purposes, according to the announced pattern for the national project[15].

Accordingly, the MoWRI will be in charge of identifying the amount of water to be used for each well (water discharge). The users will have to decide the economic feasibility of the agriculture crops to plant accordingly. However, cultivation of water exhausting crops is prohibited in the newly reclaimed areas[16]. In all cases, the agreement between the water users and the GoE will be terminated immediately, if the withdrawn water exceeded the allowed limits at any point of time or if the assign areas were used for purposes other than that agreed in the contracts.

In addition, the MoWRI proposed in its methodology to transfer the property of the wells the users, while it retains the right to monitor and evaluate the aquifers and withdrawal rates from the wells through the implementation of monitoring and control systems. Another measure to empower the ownership attitude among the users, the evaluation process will deal with the whole area as one unit (i.e. shareholding company), where every participant will be held accountable for the deficiencies and violations of others operating in the same unit.

14 Meeting with high level official in MoWRI (Dr Sameh Sakr, May 2017)
15 Meeting with high level officials in Alreef Almasry (June 2017).
16 Meeting with high level officials in Alreef Almasry (June 2017)

### 4.2.3 Promoting Private Sector Investments

Since the development of local manufacturing capacity and SMEs in the RE industry has been supported by the GoE especially in the last few years, it could be good opportunity for creating new jobs along the local value chain.

Since the announcement of FiT scheme in October 2014, the private sector investors have been showing keen interest in the RE applications. The number of qualified companies for installations and maintenance of RE systems to be connected to the grid is continuously increasing and has exceeded 180 companies (NREA, 2017). In addition, many companies are operating in the market for off-grid solutions (as SWP), for which no clear information is available in the records.

Agro-business industries are also considered important stakeholders for SWP, since most of their large farms are located in the western desert (in Wadi Elnatroon, Oases, Cairo-Alexandria desert road) and they rely on underground water for irrigation purposes and the implementation of SWP is feasible and cost efficient for the large scale installations.

### 4.2.4 Government Regulations and Incentives

The GoE has been overtaking important measures to promote RE applications in general. In October 2014, the first round of Feed-in Tariff (FiT) scheme was announced also for small scale solar PV installations. The second round of FiT was introduced in October 2016 to continue promoting these applications. Simultaneously, a Net-metering system was introduced in 2013 and it implementation started in 2014, while necessary amendments were concluded in 2017 aiming at encouraging the implementation of distributed solar PV systems. Both the FiT scheme and the net-metering could be considered mainly on the Nile valley and delta, where the national electricity grid exists already. If all conditions are suitable, the implementation of SWP systems could also generate revenue streams for farmers and hence contributing to the overall social well-being.

In addition, all RE equipment and spare parts are exempted from the customs duties, where only a flat rate of 2% applies once a confirmation letter from NREA is submitted to confirm that the imported components are eligible for exemption (Presidential decree 184/2013). In its simplest form, this incentive allows the end user (farmers) to buy the SWP systems at prices very close to the international prices and accordingly to benefit from the decreasing trend of all renewable energy equipment and components due to the economies of scale worldwide.

## 4.3 Market Challenges and Gaps

The main challenges are:

1. **Economic challenges:**

   a. Despite the fact that the costs of different renewable energy applications in general and prices of solar PV panels in specific have witnessed significant drop in the last few years due to the economies of scale associated with its wide application worldwide, the SWP applications are still expensive in terms of EGP due to the devaluation of the Egyptian Pound against different foreign currencies.

   b. The subsidized prices of other conventional energy sources (mainly diesel and partially electricity) are still imposing a challenge for the transition towards SWP, despite the gradual uplift of subsidies since 2015.

   c. The crop pattern might require farmers to cultivate low value crops, which increase the challenge to upgrade the irrigation systems, making the decision even harder for financial reasons, especially for underground water where extra cost for drilling is involved.

2. **Financial challenges:**

   a. The upfront investments in SWP systems is expensive for the majority of micro and small farmers.

   b. Lack of supportive financial mechanisms and limited financial facilities away from the banking system, especially that micro and small framers sometimes are not used to deal with banks. This might entail a social aspect, reflecting the fear of losing their land for any reason.

   c. The terms and conditions of the available financial loans are challenging to the vast majority of landholders, especially the condition related to the collaterals and guarantees, which requires the submission of a legal documents to prove the land possession and ownership. Not being able to fulfil this condition would result in disqualifying the loan application, which accordingly hinders the expansion of implementing SWP systems.

   d. Barriers to access finance: despite the new initiatives like the Green Funds (therefore availability of funds), the majority of farmers does not have access to subsidized loans mainly because submission of an official document as a proof for land tenure is a prerequisite. Therefore, new and convenient financial mechanisms are needed to boost the SWP market.

3. **Technical challenges:**

   a. Further technological enhancements and updates might be essential for SWP systems to adapt to the conditions of local market, especially the hot arid climate and dusts in remote areas (deserts).

   b. There is a lack of skilled and qualified technicians to install and repair the SWP systems in different areas, especially in the remote areas and hot spots where the potential is high (e.g. as in Siwa Oasis).

   c. The availability of low quality products in the market (from unreliable manufacturer) contributes to creating negative reputation for SWP systems among certain groups as being unreliable option and hence created resistance for further implementations.

   d. Lack of quality assurance schemes and product standardization, market supervision and control mechanism for consumers' protection schemes.

4. **Legal and regulatory challenges:**

   a. Even though different key ministries have clear strategies and goals related to the implementations of renewable energy solutions in different sectors (MoERE, MoWRI and MoALR), there is no clear ministerial mandate and insufficient coordination. This results in lack of communication, while integrated policy approach is required and necessary to promote the market.

   b. The GoE has announced different initiatives to support creating new jobs, however there is lack of clarity in the administrative process and the related information is sometimes unclear and other times conflicting or confusing.

   c. The legal and administrative processes through governmental bodies are typically lengthy and add to the complexity of the situation. A clear example is the issuance of official land tenure (proof of land possession). It usually takes place after long period of land utilization. Since this document is a prerequisite for having access to finance, this delay may have more profound impact, not just on farmer but also on the overall economy.

d. Application of modern irrigation systems (drip and sprinkler) must be mandatory by law, especially in the areas relying on underground water for irrigation, and flood irrigation must be kept to minimal.

e. Excessive use of fertilizers and pesticides must be criminalized for its negative impacts on the environment, the soil and also on the quality underground water aquifers.

f. Optimal crop pattern must be adopted through intensive exchange between MoALR and MoWRI, and cultivation of water consuming crops must be minimized or eliminated, whichever is applicable.

g. Legislations related to the over-exploitation of underground water must be amended to include quantitative and qualitative measures and clearly communicated to all participants and stakeholders.

5. Other challenges:

a. The GoE was directing its attention and support to the large scale projects (and related investments) for many years, while limited attention and marginal incentives were given to the small scale implementations (including SWP) despite its considerable potential.

b. In general, there is a lack of awareness coupled with a weak exchange of reliable information among the key stakeholders and target groups about the SWP applications, its benefits and requirements.

c. Missing and/or insufficient and obsolete data is available through administrative and governmental stakeholders, and inaccurate or conflicting information is communicated to/by the development agencies. The limited access to accurate and concrete information does not enable accurate analysis for better understanding on the current situation. Accordingly, poor planning and implementation are more likely to occur on different levels.

d. Especially for the new areas, there is a need to change the consumption behaviour/pattern of the people to be more aware and sensible with regards to the use and consumption of water for different purposes (residential or agriculture)

## 4.4 Relevant Legal and Administrative Framework for Water Sector

Law 12/1984 on irrigation and drainage regulates the use of water, including groundwater. It controls water rights, sets priorities between users, defines beneficial and harmful water uses and regulates financial aspects and penalties. The laws define the use and management of public and private sector irrigation and drainage systems including main canals, feeders and drains.

Law 12/1982 defines inter-alia public properties related to irrigation and drainage, for example the River Nile, the main canals, public feeders and public drains and their embankments. The law regulates the use of groundwater and drainage water (construction of wells or the use of drainage water and water pumps). It provides the regulations for the development of new land and the price that has to be paid for the irrigation and drainage of land.

**Relevant Executive Regulations of the Law of Irrigation and Drainage**

**Article 18:** The state authorities, local departments, other governmental or non-governmental authorities or individuals shall not be allowed to authorize or carry out digging groundwater wells whether deep or surface in all the lands of Egypt except via a license from the Ministry of Irrigation and in conformity with the stipulations set by the Ministry.

**Article 20:** The Ministry of Irrigation shall establish records at the level of irrigation districts that would include data concerning the wells authorized to be dug.

**Article 21:** . . . The Ministry of Irrigation shall conduct a periodic revision of the notifications submitted to it according to article (19). The Ministry shall also carry out the necessary examination of the wells and express its observations regarding every location and send a copy of the data sent to it and the result of the examination to the Groundwater Research Institute that follow the Water Research Center for studying and giving the final opinion in its regard.

## 4.5 Simplified Comparison between two Energy Sources

At this stage, it is useful to display a simple and conservative comparison[17] between the irrigation systems using the two main sources of energy that are relevant to this study, based on real cases and recent prices: (1) solar PV system, and (2) diesel genset generator. The typical capacity used for this comparison is 20 kWp for the SWP system (also the capacity of solar PV panels) and 25 kW for the diesel genset. These capacities are suitable for operating a water pump of capacity between 12 and 15 hp (i.e. equivalent to 15 – 20 kW).

For this comparison, the price of the pump was not considered as well as costs of other components that will be used regardless the source of energy. The calculations of the two systems are based on market prices as of August 2017, given the following assumptions:

1. **For the solar PV system:**
    a. The upfront price is EGP 280,000 (~USD 15,775); average cost per kW is EGP 14,000 (~USD 789) without the pump price.
    b. The invertor needs to be replaced at least every five years, for EGP 60,000 (~USD 3,380). The cost of three invertors was considered in calculations during the 20 years of operations.
    c. The annual operation cost is estimated to be EGP 500 (~USD 28)
2. **For the diesel genset generator:**
    a. The upfront price is EGP 75,000 (~USD 4,225)
    b. The annual operation costs include
        i. Diesel cost subject to 5% annual increase (current price EGP 3.65 per litre)
        ii. Replacement costs of air filters, oil filters and diesel filters. The estimate lifetime of each is 170 hours.
    c. The generator invertor needs to be replaced in the 12th year, for EGP 120,000 (~USD 6,760)
    d. The estimated lifetime of the diesel generator is 17,520 hours (~1,460 hour per year)

All the calculations for these two systems were done for an operational period of 20 years; all other factors are assumed to remain constant. The outcome of these calculations was in favour of the irrigation systems run by solar PV power as shown in Figure 4.2.

[17] Source: Presentation by Eng. Ossama Mokhtar in “Regional Experts Workshop on Solar Pumping” (Cairo, May 2017)

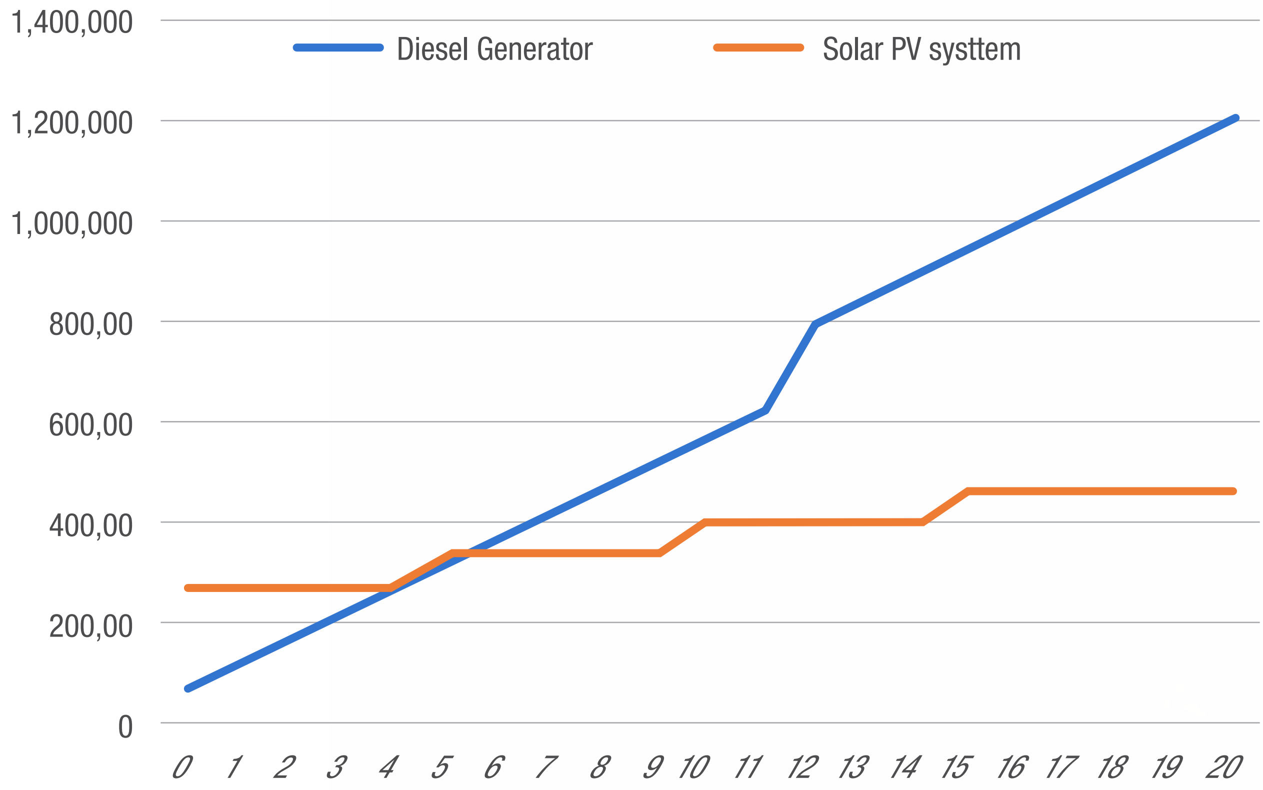


**Figure 4.2:** Accumulated expenses of two different systems (diesel generator and solar PV system)

From the graph, the breakeven point is between five and six years, after which the cost of the diesel system will increase drastically, while the solar PV system will be less expensive and more likely to be a cost saving option. Introducing more realistic assumptions to this model; e.g. increasing the diesel price more than 5% per year, will change the outcome, but the results will remain in favour of the solar PV powered irrigation system.

To ensure the reasonability and applicability of this model, further market investigations were done through companies already operating in supplies, installations and maintenance (~ 20 companies). The outcomes confirmed that the average size of the SWP systems installed over the last few years is 20 kW, mostly in the Western desert and Oases. Considering the average installation of 50 to 100 systems for each company, the average of already installed capacity of SWP systems is between 20 and 40 MW.

Therefore, for consistency, this conservative model and system's size will be used later in section 6.3.1 to calculate the socio-economic impact of using SWP systems on the local value chain and job creation.

# Potential Market Size for Solar Water Pumping

# 5 Potential Market Size for Solar Water Pumping

The statistics shows that despite the fact that the majority of the agriculture areas are located along the Nile valley and delta where the national electricity grid is available, most of the farmers either use diesel pumps or have diesel pumps as a backup. This might be attributable to the perceived less reliability of the grid power as a power of supply in the rural areas ( (EC, 2013). However, the operating conditions of the grid power supply have improved substantially since 2015, but there is no evidence that such improvement has reflected on the usage of water pumping for irrigation purposes.

Furthermore, the capacity of SWPs used for surface or river-based irrigation varies between six, eight and 10 hp, which is relatively lower than that required for shallow underground water irrigation (around 12 to 16 hp). The capacity is expected to increase for deep underground water irrigation.

## 5.1 Potential Market Size for Existing Pumps

A very conservative approach will be considered in exploring the potential size for the SWP based on the available information about diesel and electric pumps currently used in irrigation. The following few points shall highlight the conservative number and/or percentage of these pumps that could be replaced or upgraded with SWP.

### 5.1.1 Potential Based on Expected Lifetime and Efficiency

The recent statistics revealed that a total of 957,534 pumps are used for agriculture and irrigation purposes (MoALR, 2016), serving a total area of ~9,083, 531 feddans (i.e. a modest average of one pump per each 10 feddans). Around 61% and 63% of the irrigation machines and water pumps respectively (587,472, 600,454) being currently in operation while purchased more than 37 years ago. A considerable percentage of these irrigation machines and water pumps (369,937 and 400,460, ~39% and 42% respectively) are being used for at least 27 years now, as illustrated in Figure 5.1, which eventually need to be replaced.

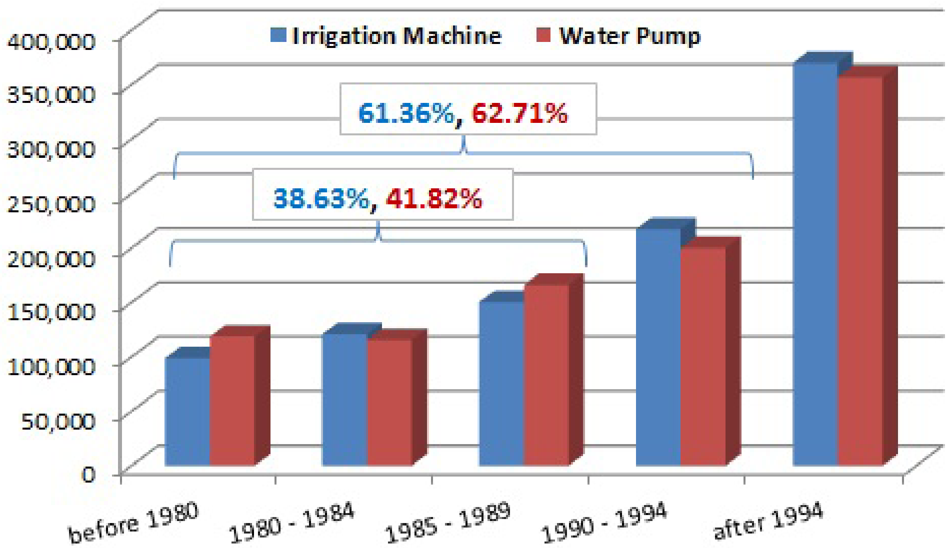


**Figure 5.1:** Purchase year for available irrigation machines and water pumps (2015)

The GoE could adopt an incentive scheme to replace the old machinery (motors and pumps), which must be operating with deteriorating efficiency and therefore consuming excessive amount energy during operations to produce decreasing amount of water for irrigation.

Since almost 85% of these pumps are used for surface irrigation, where the fragmentation of landholdings is more likely to be the case, special attention need to be given in design the respective incentive schemes to address the main challenges for the majority of landholders.

### 5.1.2 Potential Based on Mobility

Out of the existing total of 957,534 pumps being used for irrigation with different capacities, around 175,016 pumps are fixed (18.3 %) while 782,518 pumps are portable (81.7%, will be discussed in 5.1.3). For the fixed pumps, installation of solar PV on the roof of the protecting structure could be especially advantageous to minimize the risk of theft.

From Figure 5.2 (MoALR, 2016), it is clear that the majority of fixed pumps are located in Lower Egypt (~104,041 - 59.45%) and 33,824 (19.33%) are in Upper Egypt. Therefore, these two locations could be considered for replacing these fixed pumps with SWP systems.

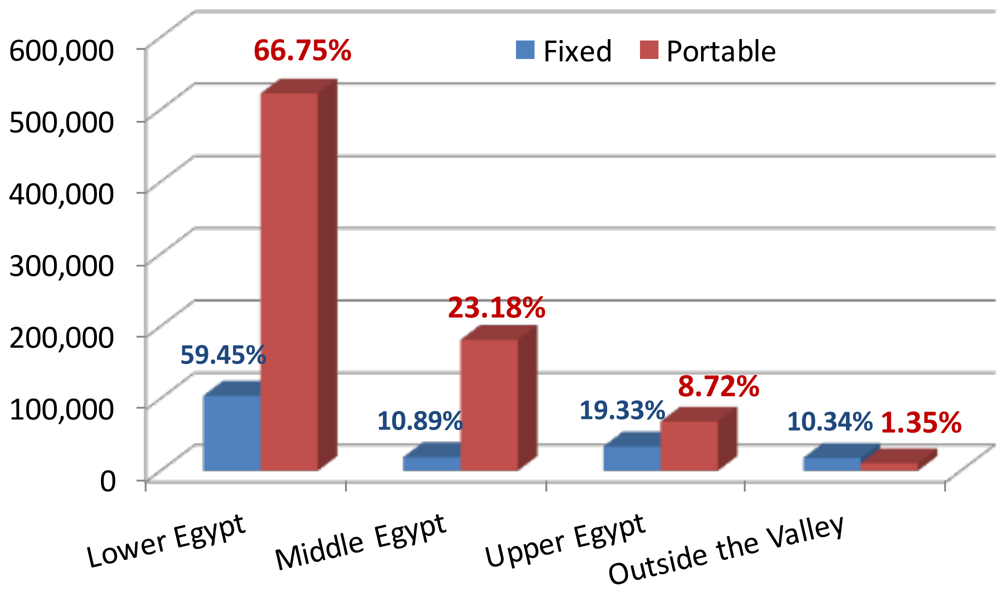


**Figure 5.2:** Fixed and portable irrigation machines in different governorates in Egypt (2015)

It is also worth mentioning that the capacity of the fixed pumps falls in four main categories: (1) less than 15 hp, (2) between 16 and 25 hp, (3) between 25 and 45 hp, and (4) more than 45 hp. The share of each of these categories is 37.99%, 31.47%, 15.87% and 14.67% respectively.

Since the majority is of capacity less than 25 hp (**121,561 pumps,** ~69%), this introduces another advantage related to the space needed for installing the panels (smaller space for smaller capacity), therefore could be considered for SWP solutions.

It was mentioned in section 2.3.1 that the fixed irrigation machines of relatively higher capacity are mostly located near the branch and distributary canals, for lifting water to the minor canals (mesqas) serving a certain district or village.

Accordingly, the total of **51,934** (~29.67%) fixed pumps inside the valley could also be considered reasonable hotspots for SWP applications using surface irrigation.

### 5.1.3 Potential Based on Applied Capacities

The share of portable (or mobile) pumps is 81.72% of total irrigation machines, which have different categories of capacity as in Figure 5.3 (MoALR, 2016).

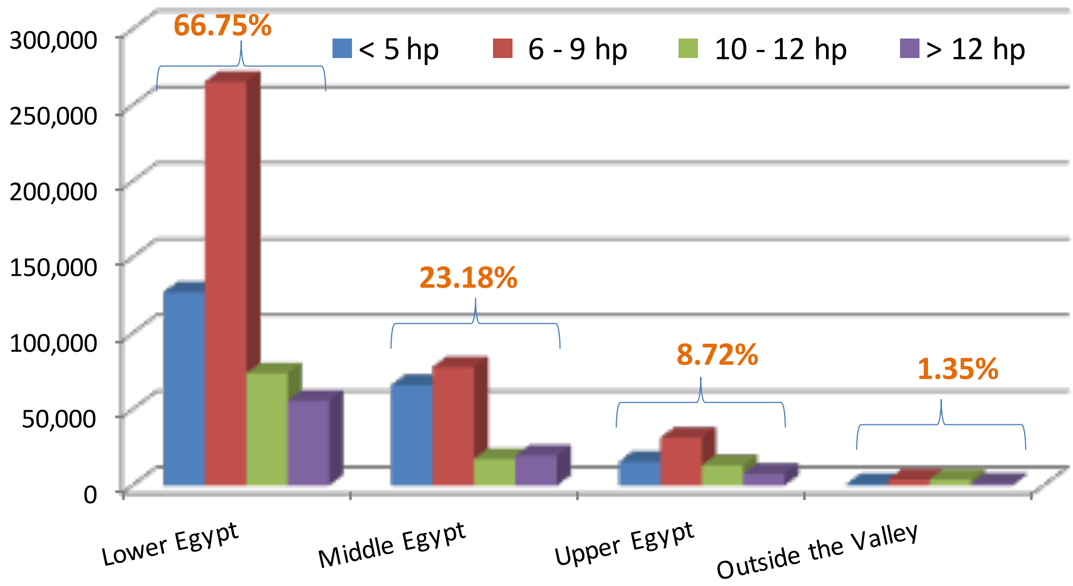


**Figure 5.3:** Different capacities of **portable** irrigation machines in different governorates in Egypt (2015)

The majority of the portable pumps are of capacities of the two smallest categories: (1) less than 5 hp (26.84%) and (2) between 6 and 9 hp (48.44%). Within these two categories, almost the half (in specific **392,639 pumps,** 50.18%) is located in Lower Egypt. This marks Lower Egypt as one of the **hotspots** that could be targeted for micro scale SWP applications to be used for surface irrigation (also for all capacities). The estimated capacity for SWP systems matching the size of these pumps should be between 15 and 20 kW.

In general, the main governorates with highest numbers of irrigation machines are: (1) Behera, (2) Sharkia, (3) Gharbia, (4) Kafr Elsheikh and (7) Menofia in Lower Egypt, and (5) Beni Suef, and (6) Menia in Middle Egypt (numbered in descending order).

### 5.1.4 Potential based on Landholdings

The fragmentation of landholdings is remarkable, especially for the areas within the Nile valley. For identifying the market potential and hotspots for different categories of possessions (landholdings), it is important to identify the number of possessions within each governorate, and then relate to it the different capacities and types of pumps being used for these possessions.

However, since it was not easy to put all these details in one informative illustration, important indications will be deducted from the following illustration based on the available information, which could be useful to highlight few in-depth aspects related to this topic and accordingly inspire more detailed market analyses in the coming few years.

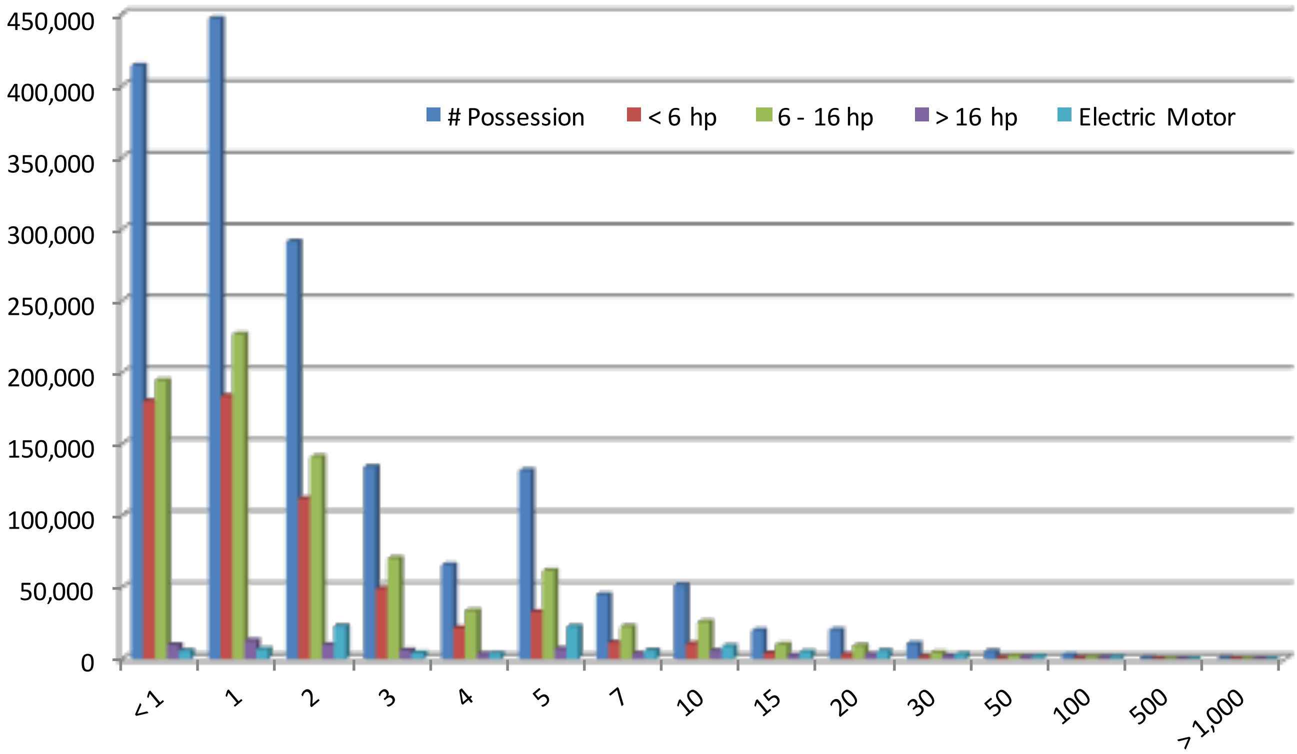


**Figure 5.4:** Categories of landholdings in all governorates using different types and capacities of pumps (2015)

Figure 5.4 (MoALR, 2016) classifies different capacities of pumps on different categories of possessions in all governorates, for which the reported total possessions were 1,638,623 in the old and new lands of all 28 governorates in Egypt (MoALR, 2016). It is important to note that this number is different from the total possessions mentioned earlier in section 2.1.4, since this number refers only to the agriculture possessions according to the applied machines (owned or shared) for different categories of landholdings in all governorates.

The fragmentation pattern is obvious once more in this regard, since the majority of possessions (1,482,683, 90.48% of total possessions) are for the smallest categories of five feddans and less. For these categories of possession (i.e. five feddans and less), the share of the three mentioned pumps' capacities: (1) less than 6 hp (94.80% of possessions using this capacity, 35.31% of total possessions), (2) between 6 and 16 hp (90.57% of possessions using this capacity, 44.37% of total possessions), and (3) more than 16 hp (71.76% of possessions using this capacity, 2.97% of total possessions). These categories are facing the biggest challenges because of land fragmentations. With regards to the pumps, the capacities less than 6 hp and up to 16 hp seem to be mostly applied. This deduction prevails also when looking deeper into each governorate as in Figure 5.6. The only exception is in North Sinai and Alwady Algaded (New Valley), where the electric motor is the mostly used compared to others.

However, the fragmentation pattern differs for the electric motors, where the highest share of possession is mainly for the categories of two and five feddans (together **45,303** possessions, 46.41% of possessions using this type). If these possessions go for SWP solutions, it would be possible to use the national grid as storage for the excess generated capacity, therefore adding an additional revenue stream to these landholders.

From this analysis, it is clear that there is a big potential, especially for the smaller categories of possessions and smaller size of pumps, which requires innovative solutions to promote and facilitate the use of SWP applications. An example of these solutions is the mobile solar PV panels that could be used to power water pumps of small capacity, as shown in Figure 5.5, which could be an ideal replacement for operating and powering the small size portable water pumps used in surface irrigation.


**Figure 5.5:** Mobile (or portable) solar PV panels suitable for operating the small size water pumps (Source: Powering Agriculture)

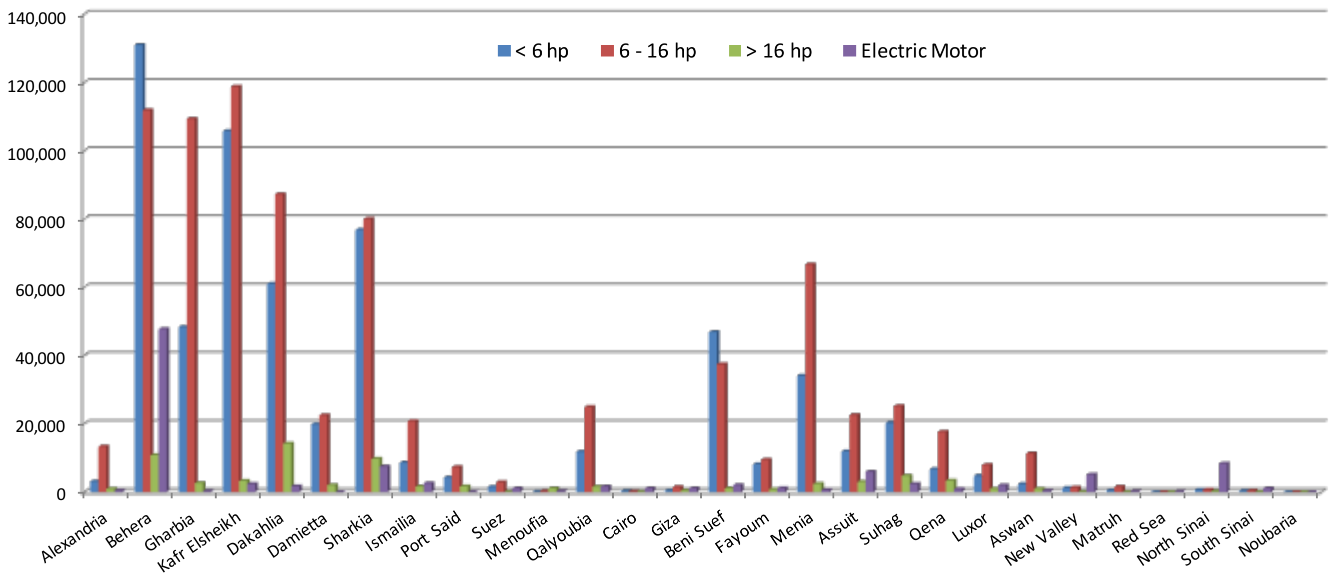


**Figure 5.6:** Applied irrigation machines (pumps) with different types (diesel and electric) and different capacities in all Governorates (2015)

Considering the total possessions with different number and capacities of pumps (MoALR, 2016), the majority of possessions (1,030,248 – 65.27%) is located in the following top 5 governorates: (1) Behera: with a total of 301,388 possessions (19.09%), (2) Kafr Elsheikh: with a total of 230,132 possessions (14.58%), (3) Sharkia: with a total of 174,057 possessions (11.03%), (4) Dakahlia: with a total of 164,149 possessions (10.40%), and (5) Gharbia: with a total of 160,522 possessions (10.17%).

## 5.2 Potential Market Size for the New National Reclamation Project

The national project for the reclamation of a new three million feddans has started with the first phase covering 1.5 million feddans. This is the main potential market for SWP applications using underground water for irrigation, apart from the potential of replacing existing pumps. Therefore, the selected locations can be considered one of the **hotspots** for SWP systems using underground water, especially because these are mostly located in remote areas and in the western desert, hence off-grid solutions are essential for irrigation purposes.

As shown earlier in Figure 2.15, there are 139,470 deep well's pumps in operation, which are mostly located either on the trim of Nile valley and delta and in the western desert. In total, only 28,686 pumps are reported for the areas outside the valley (~3% of the total pumps).

For simplicity, if we apply the same modest average of 1 pump serving 10 feddans[18] (although it could be five feddans for underground water), this means that **at least 150,000 pumps** are required to serve the first phase of this project (more realistic estimate is 300,000 pumps for underground water irrigation). The capacity of these pumps depends of the depth of the underground water, the allowed withdrawal rate, and the water requirements for the cultivated crops (among others).

## 5.3 Potential Market Size in the Public Sector

Reference was made earlier in section 2.3.1 to the huge pumping stations along the Nile River, the main and secondary canals to regulate the water flow. These pumping stations must operate 24 hours per day, and are mostly relying on the national electricity grid and slightly on diesel.

Since the MoWRI is in charge of these pumping stations, it could also adopt a "leading by example" approach especially for surface irrigation and implement SWP solutions to run these stations even partially during the 8 to 10 hours of the daily sunshine. In this case, the national electricity grid could act as a "storage unit" for the installed solar PV systems, hence reducing the overall cost of the SWP systems. Furthermore, the MoWRI could benefit from the net metering scheme to reduce its monthly electricity bill, since the installed SWP systems could provide a revenue stream from the installed capacity.

This shall be an important recommendation for the MoWRI to consider, especially that most of these huge stations have enough space (also building roofs) to install the solar PV panels. Besides, it might be possible for the MoWRI to be granted reasonable funds to support this initiative.

Furthermore, the initiative of operating the government wells using SWP reflects also an existing market for SWP solutions for underground water. Unfortunately, it was not possible to have information about the government pumps used for surface irrigation to consider its potential.

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18 Meeting with high level official in MoWRI (Dr Sameh Sakr, May 2017)

# The Local Value Chain for Solar Pumping Solutions

# 6 The Local Value Chain for Solar Pumping Solutions

The applications of SWP systems serve different sectors, mainly agriculture, irrigation and energy. It extends also to the local industry (assembling solar PV panels, manufacturing pipes, wires, etc.), trade (import; wholesale and retail), construction (mounting structure and foundations), agro-business and industry (private sector), as well as large farming organizations (e.g. for medical herbs) and small farmers, all together are important stakeholders in the Egyptian irrigation system (Wolters, et al., 2016).

Accordingly, it has profound impact on different levels of the economy, due to its diversified and multi-dimensional value chain. Therefore, SWP not only provide a reliable, cost-effective and environment friendly irrigation solution, its benefit extends to include improved livelihood, increased social welfare (poverty alleviation, emissions reduction) and reduced centralized infrastructure and spending on subsidizing fossil fuel (IRENA, 2016).

Besides being a cost-effective solution, when SWP solutions are coupled with secured access to the underground water, it contributes to increasing the agriculture productivity, agriculture revenue and accordingly food security (FAO, 2014).

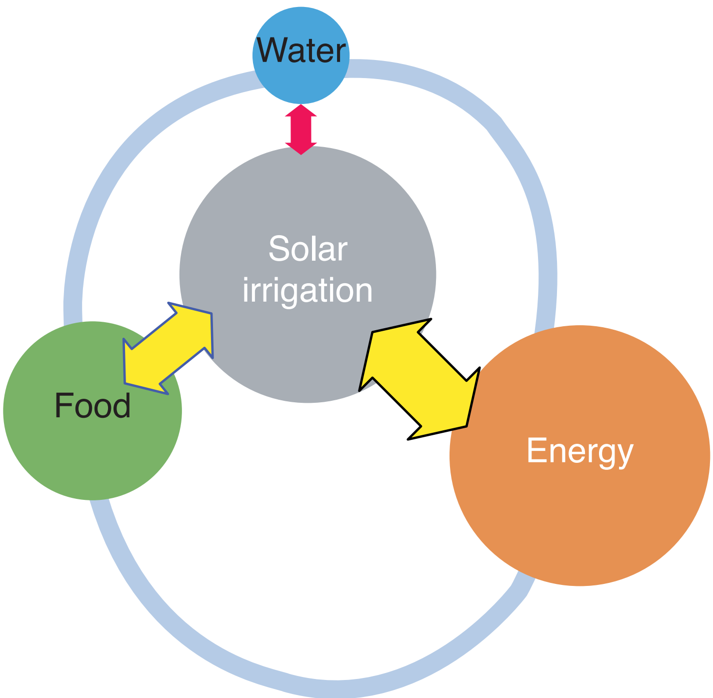



**Figure 6.1:** The water-energy-food nexus and SWP for irrigation using underground water

Even though the assessment of the SWP systems' impact on jobs' creation and local value chain is considered important and necessary step to boost the market, it was extremely challenging, especially because the available literature on the impacts of RE deployment on employment and potential of jobs' creation addressed the impacts of different RE technologies (such as solar energy, wind, etc.) rather than a specific application (like SWP solutions) of one technology (i.e. solar PV); as well as addressing the socio-economic impacts along the whole value chain starting with manufacturing, rather than focusing on the impacts on the local value (i.e. only part of the whole value chain). For this reason, a very conservative bottom-up assessment approach will be considered in addressing this issue, focusing mainly on the jobs attributable to SWPs that are more likely to be created locally, based on real applications and hands-on the local market to ensure transparency and simplicity.

## 6.1 Socio-Economic Impacts along the Solar Pumping Value Chain

The purpose of this section is to identify the socio-economic impacts in terms of the number of jobs that could be created per unit of the installed capacity of SWP systems (in megawatts) one year and the extent of creating local value along the chain for SWP solutions.

Based on available literature, jobs related to RE technologies in general can be classified into three main categories: (1) direct jobs, (2) indirect jobs, and (3) induced jobs.

The **direct jobs** refer to the jobs created and directly related to SWP solutions, for being considered the core activities in concern. These jobs include systems' design, installations, operations and maintenance for SWP system, while these jobs would include also manufacturing, assembly and site preparation if the solar PV technology was considered. The **indirect jobs** refer to other jobs created at a secondary level to support the SWP applications, such as site preparation and civil works, electric connections, imports of SWP systems and components, transportation, technical and vocational training instructors, financiers, public regulators, and the like, while these jobs would include also extraction and processing of raw materials, sales and marketing and local manufacturing capacity in material supplies (among others) if the solar PV technology was considered. The **induced jobs** refer to the jobs arising from the economic activities for both, directly and indirectly created jobs, even on industries and sectors not related to RE but has considerable potential for job creation.

The available literature (e.g. (Zwaan, et al., 2013)) estimated the indirect jobs using simple multiplier of 0.75 of direct jobs in the MENA region, while only few studies described the indirect employment factors for different phases of deployment (Cameron & Zwaan, 2015). Besides, the employment factor[19] for the solar PV technology was characterized of being of a wide range of variance between 3.9 and 23.6 per MW installed compared to other technologies like wind (Zwaan, et al., 2013). Considering that sticking to a strict definition for the "direct" and "indirect" jobs might result in disregarding certain jobs along the local value chain, both types of jobs created (direct and indirect) will be considered in the following analysis and referred to as **one number** only for simplicity and clarity of the presented analysis. However, since the "induced jobs" are hard to be estimated accurately, it is considered beyond the scope of this study, but it is highly recommended to be further investigated in other more specialized economic studies (for example to use for Input-Output models).

## 6.2 Composition of the Solar Pumping Value Chain

The main components of the SWP systems are mostly imported; only limited components are manufactured and supplied through local industries (the supply side of SWP systems). Therefore, the expected impact on the local value chain will be mainly in the distribution and implementation (the demand side of SWP systems).

The main important components and key stakeholders of the SWP systems are summarized in Figure 6.2, which include:

1. **Manufacturers** and suppliers of the main system components (solar PV panels, inverters and DC controllers, and water pumps). All or most of the parts of the systems' components are manufactured abroad and its local impact is expected to be limited to assembling activities, if applicable.
2. **System integrators** (also known as suppliers or installers) buy the respective components from the importers (seller), design the SWP systems according to needs, based on which the installation works are done, followed by operations and regular maintenance.

[19] Employment factor refers to the number of jobs derived from a certain renewable technology investment or capacity (Cameron & Zwaan, 2015)

In literature, both manufacturing and installations were combined with respect to the number of jobs created, which are expressed in terms of person-years per MW, while jobs related to operation and maintenance are calculated for the entire lifetime of the SWP systems and are expressed in terms of number per MW (Zwaan, et al., 2013).

3. Importers or importing companies import different components from manufactures to make it available for sale in the local market. The importing activities are not specific to certain technology or equipment, but rather general for all systems, machines and products.

Most of the SWP systems' components are imported. The list of commonly used in the market is available in Table 3.1 under section 3.1.2. However, there are some local factories operating in the production and assembly of the solar PV panels and RE systems at relatively early stages, which might belong to the manufacturing process, such as the Arab Renewable Energy Company (ARECO), affiliated to Arab Organization for Industrialization (AOI), Benha Electronics, ARE Group, Power Field, Sun-Prism factories and few others. However, there is no clear information related to their local market share for solar PV panels to consider a factor for their contribution in the market of solar PV technology as manufacturer, hence its impact is expected to be minimal on jobs' creation with respect to SWP systems.

In all cases, for these stakeholders to operate effectively, their teams must be qualified enough to carry out the assigned tasks. In this regard, **training institutions** have an important role to play in order to equip the local market with qualified labour force. They need to offer specialized and professional training courses for installers, technician, electricians and others.

In addition, the system integrators could receive loans or financial support either directly from funding and **financing institutions** or through **local banks.** In this respect, also the financiers and finance officers need to be qualified to handle this market segment and satisfy existing market needs through innovative and reasonable financial products. It is expected that more jobs could be created for these stakeholders, as the market for SWP applications increases.

Furthermore, there are other stakeholders supporting the installation phase and have therefore impact on the local value chain. These include:

1. Manufacturer of cables and wires for the interconnections.
2. Manufacturer of pipes and fittings for the irrigation network (drainage, sewerage and sanitation).
3. Manufacturer of mounting structures for setting up the structures for the solar PV array.
4. Contractors for civil works and construction for the foundations of the solar PV array and pumps.

Most of these components are either already manufactured locally such as wires and cables (except the DC cables), irrigation network fittings, and sometimes the metal foundation for mounting structures) or have the potential of being manufactured in the local market if given enough attention and adequate support. Any increase in the number of jobs employed by these stakeholders and attributable to boosting the applications for SWP would contribute to creating local value and therefore should be considered later in the calculations for the jobs created (no clear numbers are available in the meanwhile).

With all these main stakeholders acting in the local market, the buyers (landholders, farmers, end users) can contract the system integrators to start the system design based on certain inputs (for example: flow rate of water, amount of water required for certain crops, head depth of pump, solar irradiation in the site, number of hours for sunshine and others). Once the system design is conducted, the SWP systems could be installed by the technicians, the wiring to be done by electricians, the pipes and irrigation network fittings by plumbers, mounting and foundation by contractors and civil workers. This is where and how the local value and employment opportunities are created, not only in the agriculture sector, but also in other businesses and services. Accordingly, promoting cultivation and agriculture activities promote a series of activities, like the constructions (for foundations), agrarian services (like crops' drying, storage, cooling, etc), in addition to transportation of agriculture products (in cooling trucks), as well as export of food products to different countries, and therefore contributing to further creation of jobs (indirect to the SWP installations, but contributing to local value chain).

All these stakeholders are operating in the market within the legal and regulatory framework governing all these activities. Therefore, the GoE in general and the key ministries in specific (MoALR, MoWRI, MoPNR, MoERE, MoTI) are indirect contributors to creating local value, paving the way to upscaling the SWP applications through imposing the ideal and reasonable measures, laws and policies required for promoting the SWP market. In doing so, theses ministries must also have well informed and highly qualified employees to manage this challenging and critical portfolio as efficiently as required.

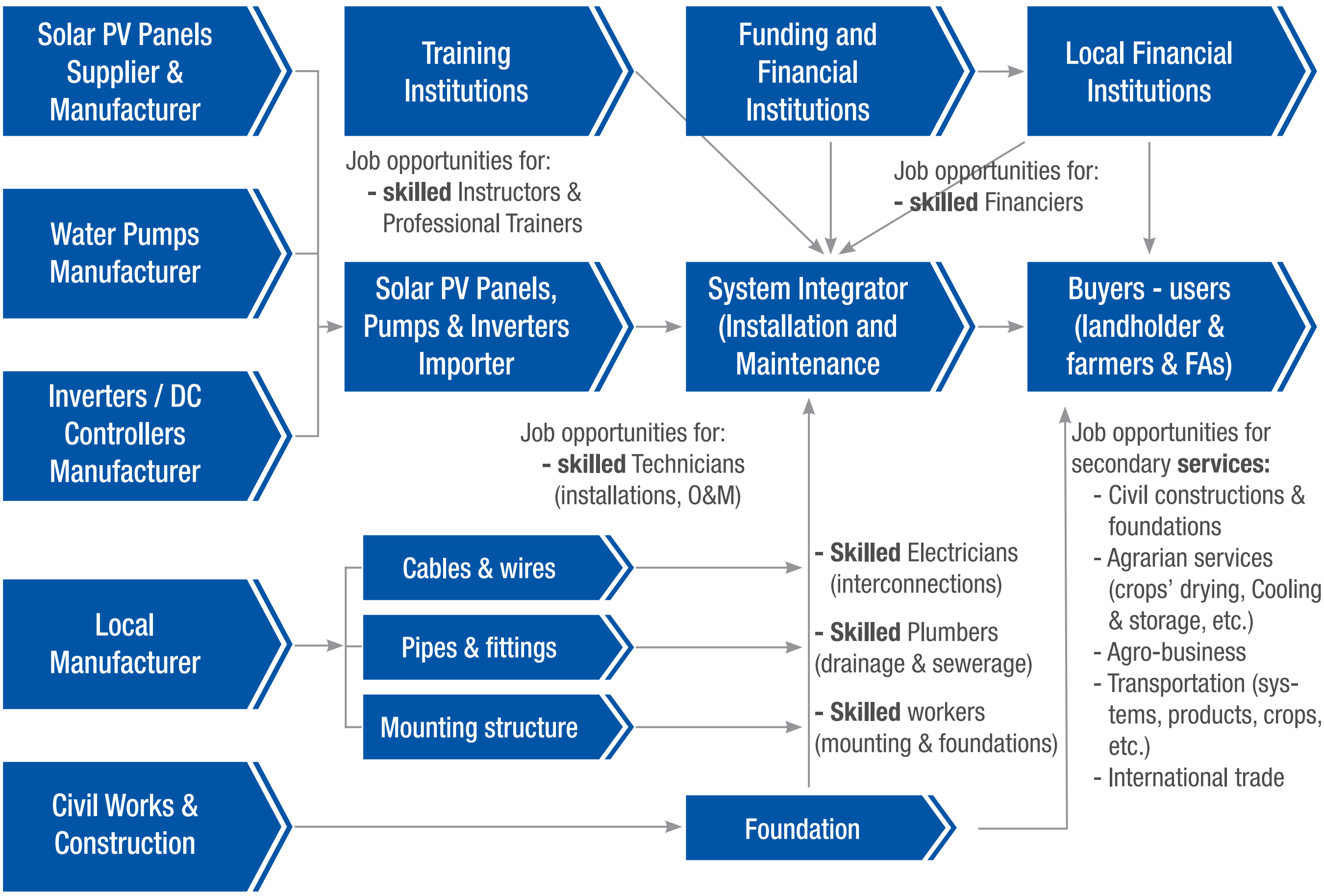



**Figure 6.2:** Overview of key shareholders, main components and areas for job opportunities along the local value chain of SWP systems

## 6.3 Potential Socio-Economic Impact on Local Workforce

To estimate the employment impact, it is important first to quantify the relevant and required tasks in terms of working days and/or hours for different stages along the local value chain. For this purpose, a very conservative estimation will be applied based on real applications and practical experience regarding the following relevant points and assumptions.

### 6.3.1 Potential Impact on Skilled Workforce

In order to estimate the potential impact on the workforce expressed as total jobs (direct and indirect jobs together), the following aspects and assumptions will be considered:

1. **The pump size:**
   Since the majority of the available diesel pumps are of capacity less than 15 hp (~764,500 pumps, 79.84%), of which 91.3% is less than 12 hp (698,010 pumps, 72.90%), the following estimation will consider converting diesel pumps of capacity 12 hp (i.e. 15 kW) to SWP system **of average size 20 kWp** (solar PV panels) building on the previous model in section 4.5.

   A SWP system of this size and capacity could be used for regular daily irrigation (~6 to 8 hours) for:

   a. surface irrigation and shallow underground water, like in the Nile valley and delta (Q=723 $m^3$ per hour, H=4.5 m)

   b. moderate underground water, like in the oases region (Q=43.5 $m^3$ per hour, H=75 m)

   c. deep underground water, like in some areas in Sinai and Western desert (Q=10.85 $m^3$ per hour, H=300 m)

   Where Q refers to the water flow ($m^3$ per hour), H refers to the pump's head in meters (m); and m is the depth in meters (m).

   The average cost of the SWP system of size 20 kWp is EGP 400,000 (~USD 22,535), including the pump's price, transportation and other related costs. The variation in the transportation costs would either relatively decrease the total cost for the areas in Lower Egypt or relative increase the total cost for the areas in Upper Egypt (due to the distance and time required to reach the location).

2. **The skilled workforce required for SWP system's installation:**

   a. **Installation:** usually the installation of 20 kW of SWP system requires **two technicians**

   b. **Electric connection:** for the suggested system, **only one electrician** is required to set up all the wiring, cables connections and testing for the system.

   Accordingly, the size of an installation team is ~2.5 persons, working in teams or as independent companies (i.e. 5.5 man-days per system). Through the lifetime of the SWP system (~20 years), the installation team shall contribute also to the regular checks for operations and maintenance (O&M) activities.

   c. **Pipes and irrigation network fittings:** are mainly for extending pipes to distribute water to the desired area. Skilled plumbers should carry out this task before the systems' installation. The number of days required for this task depends mainly on the depth of water, which will determine the length of the piping network required for the SWP system.

   d. **Civil works and construction:** this is done mostly to setup the solar PV array and the pumps (usually referred to as "mounting"). These activities include site preparation and mounting (partially or fully). The number of days required depends mainly of the terrain type and topography of the selected sites for installations.

e. **Transportation and handling:** the 20 kW system is composed of 80 solar PV panel, which must be carefully transported to the location using truck and crane (or forklift), as well as skilled workers to handle these panels carefully to the site, uncover and clean the panels to be ready for installations and operations.

Usually, there is one team for these supporting activities within the installations' company. The average size of supporting team is around **six persons** to accomplish different contributions and tasks, if these activities are planned to be concluded within seven days. Reducing the size of this team will result in extending the period required to complete these activities (i.e. 3 persons would take 10 to 15 man-days to finish these activities).

3. **Time required for different tasks per SWP system:**

   a. Installations usually takes between **2.5 and 3 days** for installation of one system (in total 5.5 - 6.5 man-days)

   b. Other tasks and work excluding installations would require on average **~7 days** for completion, especially for the foundation to dry (on average 12.6 man-days)

   Therefore, it takes an average of **18.13 man-days** to install one SWP system of average capacity 20 kW (i.e. 18.13 man-days per SWP system).

4. **The number of pumps to consider:** Since a very conservative approach is being considered, the analysis will consider only 500,000 diesel pumps as a total and apply a conversion rate of only 1% per year. In other words, only **5,000 diesel pumps** of size 15 hp shall be converted into SWP systems of an average size 20 kW yearly (i.e. expected installed capacity of 100 MW for SWP systems every year).

5. **The number of installed SWP systems:** Based on this information, it is expected to install SWP systems of total capacity 100 MW every year; weekly installations equivalent to around 2.08 MW is required. Given that one working year has 48 working weeks; therefore around <u>104 SWP systems</u> could be installed every week.

6. **The estimated number of technical jobs created:** Since every installed SWP system requires 2.5 technical persons (one team), therefore every week a total of around <u>260 persons</u> (technical jobs) is needed. In addition, 2 SWP systems could be installed weekly, leading to <u>130 SWP systems</u> installation per week to be served by around <u>52 technical teams or installation companies</u> (each company with one technical team of 2.5 persons) operating in the market.

### 6.3.2 Potential Impact on Services

The installation of SWP systems involves different services, which accordingly stimulates the creation of more jobs along the whole process, such as:

1. **Site preparation:** sometimes the location needs preparation work to be ready for the mounting. In case the site is on roof-top, it might also need support to carry the planned capacity. At this stage, all the civil work is done. (<u>two persons</u>, 1 man-day each)

2. **Mounting:** it could be partial mounting (i.e. not including the metal structure for the panels) or full mounting (i.e. including the metal structure). (<u>two technical persons,</u> 2.5 man-days each and <u>one electrician</u>, 0.5 man-day)

3. **Transportation:** relative big trucks are required to deliver the 80 panels to the selected location. Skilled worker are needed to arrange these panels properly in the trucks to avoid any damage during the journey. (one person, driver for truck, 1 man-day)

4. **Lifting:** cranes (or forklift) are also needed during the loading and unloading of trucks, with the help of skilled worker to avoid damaging the panels during this process. (one person, driver for crane, one man-day)

5. **Carriers:** once the solar panels are delivered, it needs to be brought to the site, get uncovered to be ready of installation. This process must be done careful, since it involves direct contact with the panels. (four persons, two carriers for loading and two for unloading, 0.5 man-day each)

6. **Site cleaning:** to dispose waste resulting from uncovering the panels and other civil activities, for the installation team to start working (one person, ~0.25 man-day).

7. **Guarding:** once the system's components are delivered to the site, a guard would be assigned to watch over the site to prevent robbery. Later on, this guard will protect the system from potential theft. (one person, for each installed SWP system)

8. **Operation and maintenance:** is necessary to confirm that the system's performance is fulfilled. Therefore, operations must check regularly for: (1) the pressure gages to ensure the pump head is fulfilled; and (2) the flow meter of the SWP system to ensure that the water supply needs are met. On the other hand, the maintenance covers mainly cleaning the solar PV panels; either dry or wet cleansing (varies depending on the season and weather). The jobs created for O&M are usually calculated over the whole lifetime of the SWP system (one person).

In general, the team in charge of these supporting activities starts with sites' preparations in different locations, in parallel to the installations taking place elsewhere. Since the estimated time required for each task of the supporting activities varies from the estimated time required for the technical team (almost double the time is required for the supporting activities compared to that of the technical installation per SWP system), it is necessary to convert the time required for these tasks to man-years, to facilitate the calculation of the expected number of jobs to be created.

Following the calculations method in available literature (Cameron & Zwaan, 2015), the outcome shows that for every one MW installation of SWP systems around 1.09 technical jobs and 3.5 supporting jobs could be created per one MW of installations (in total 4.59 man-years). These calculations produce an employment factor of 0.23 jobs per MW installed over the expected lifetime of the SWP systems (20 years). These results are shown in Figure 6.3.

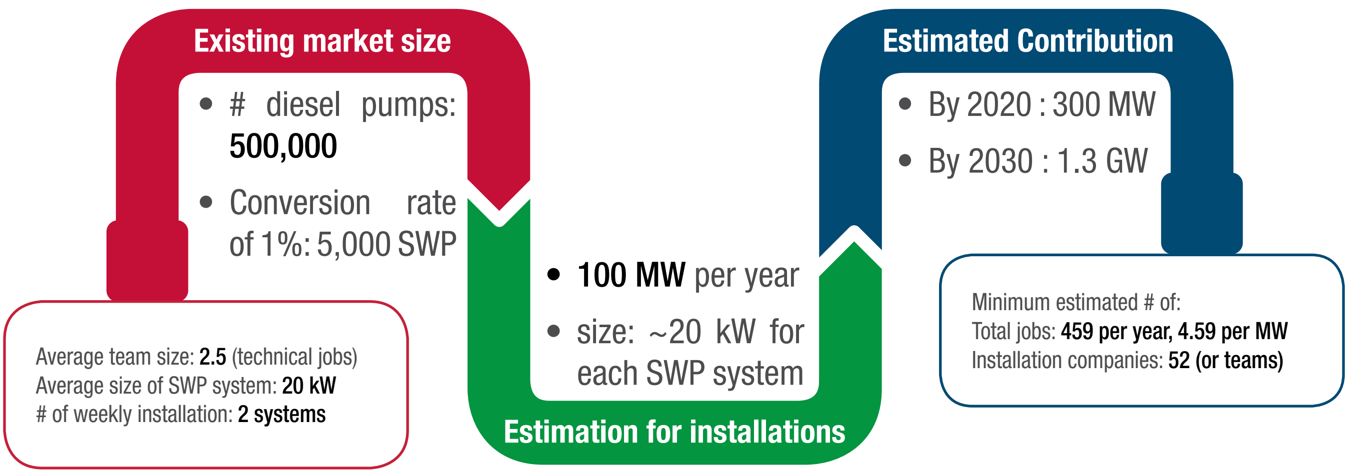



**Figure 6.3:** Very conservative estimation for expected number of jobs' creation from installation of SWP systems

Figure 6.3 summarizes the previous assumptions and calculations. It is clear that the conversion of 5,000 diesel pumps every year to SWP systems requires having 52 technical teams or installation companies operating actively in the market (i.e. in total 130 technical jobs each year) to satisfy the market needs for installations and later for operation and maintenance purposes and 329 support jobs for SWP installations per year. In other words, a total of 4.59 jobs are expected to be created <u>for every MW installation</u> of SWP systems (around 1.09 technical jobs and 3.5 other jobs).

Based on this analysis, the implementation of SWP systems reflect an employment factor for installation jobs of 4.59 per MW installed, while the employment factor is 0.23 jobs per MW for O&M over the expected lifetime. These numbers lie within the range for solar PV that was estimated for the Middle East to be between 3.9 and 23.6 man-year per MW for installations and between 0.1 and 0.7 jobs per MW for O&M over the expected lifetime (Zwaan, et al., 2013) and hence this number seems to be reasonable, although very conservative.

This conservative model could be expanded further to cover wider range of activities contributing to the local value chain, whenever the numbers are available to be considered. For example, the mounting and foundation activities could promote local industries concerned with the production of proper frames and tracking systems (automatic and manual) for the solar PV panels. Other small components of the SWP systems would also indirectly promote local industry (pipes, irrigation network fittings, wires, cables and others). The jobs created from these activities are usually considered "indirect jobs" (section 6.1). On the other hand, all the jobs that could be created later on based on the outcomes of the installed SWP systems, including agro-business, agrarian services (as crops' drying, cooling and storage, etc), fishery (in case of using storage tanks as fish ponds) and also international trade (in case of exporting crops to different countries) could be referred to as "spill-over" effects of SWP rather than "induced jobs", which are more complicated in calculations and estimations. For this reason, the estimation of the expected number of induced jobs is beyond the scope of this study.

### 6.3.3 Potential Impact on Different Stakeholders

This conservative approach will not only increase the demand on skilled labour (especially the technicians and electricians), but also increase the demand on specialized practical and professional training (i.e. more indirect jobs in training institutions).

The market potential will also impose an increasing demand on innovative financial loans or incentives, which accordingly has the potential of generating indirect jobs in local (and international) financial institutions.

Furthermore, promoting the market requires dedicated efforts on different governmental bodies and in different ministries, therefore generating indirect jobs in respective ministries and authorities.

## 6.3.4 Potential Impact based on Crops' Pattern

Farmers are following free cropping pattern since 1990. Therefore, cultivating crops with higher net returns per feddan is influential factor for the conversion to SWP applications to be feasible.

In Figure 6.4, a comparison between the total costs (including rent) and average net return (after deducting all costs) per feddan is illustrated for selected winter crops. For the ease of reference, the amounts are calculated in USD based on the announced exchange rates for the fiscal year 2014-2015 (USD 1 = EGP 7.70)

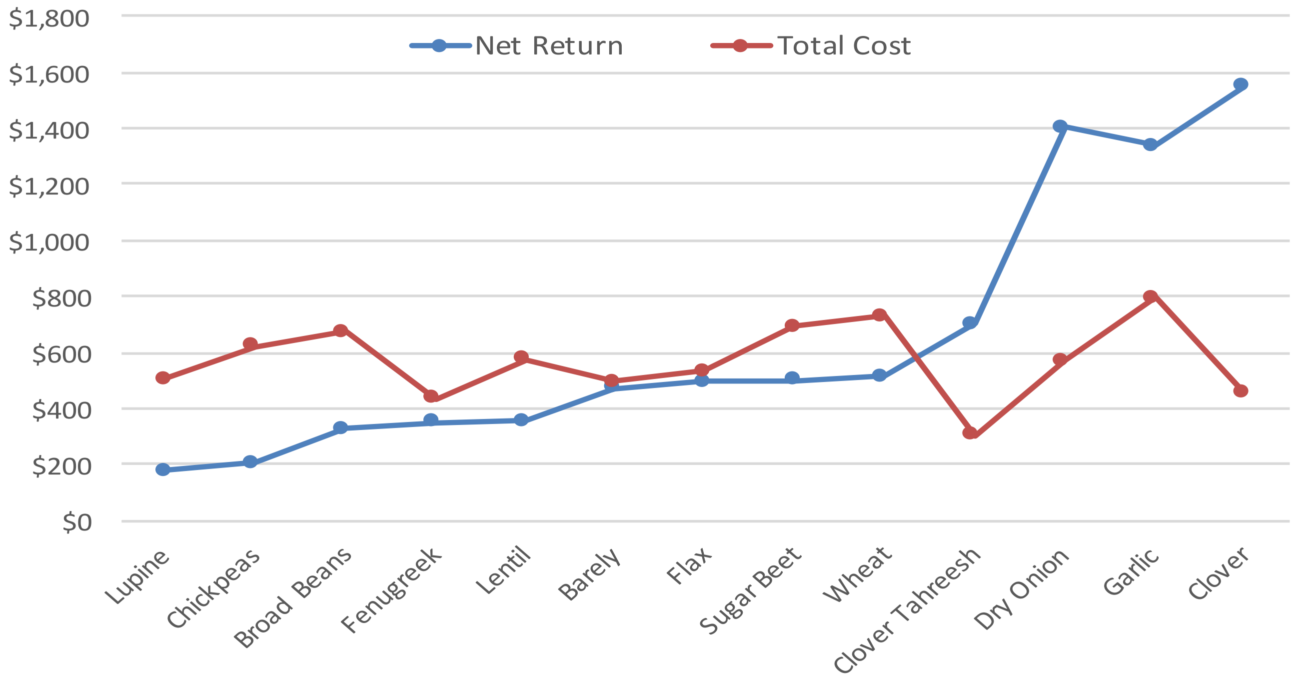



**Figure 6.4:** Average of net return and total costs for the main winter crops per feddan (2014/2015)

The same comparison was done for the medical and aromatic plant as shown in Figure 6.5, also in USD using the same exchange rate mentioned above.

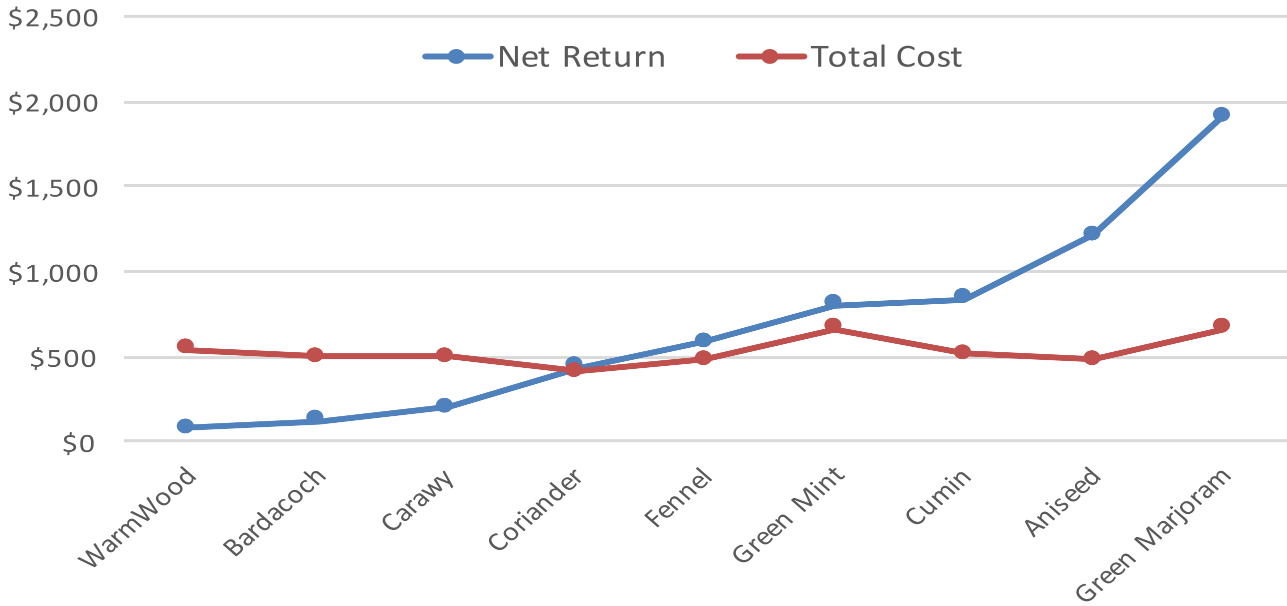
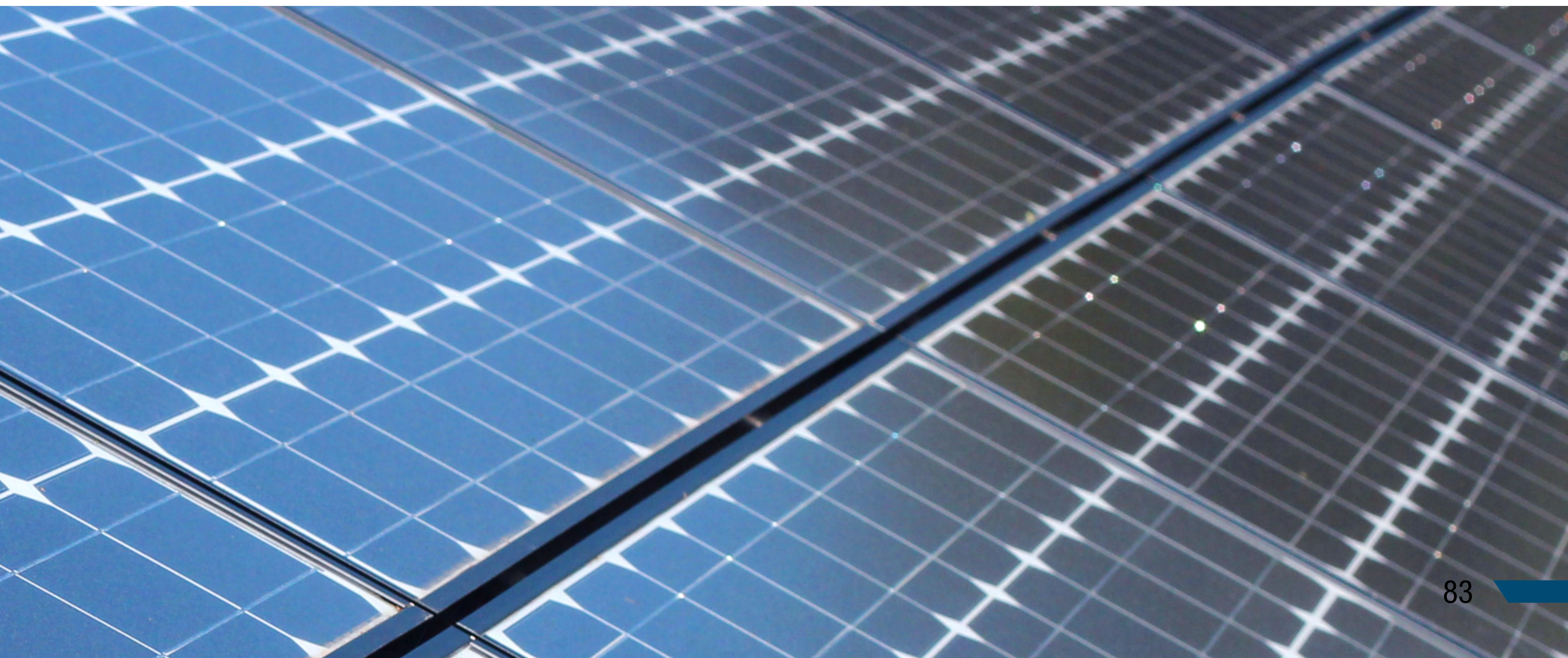



**Figure 6.5:** Average of net return and total costs for the main medical and aromatic plants per feddan (2014/2015)

The net returns of the cultivated crops (per feddan) is very important aspect in calculating the market potential of SWP applications, for two main reasons (1) to calculate the expected payback period for the SWP systems based on the expected cash inflow for each landholder, and (2) for the financial institutions to determine the bankability and credit worthiness of the landholder or farmer (especially for the evaluation of loan application) based on the expected cash inflow during the lifetime of the loan.

Furthermore, the total area to be served by the SWP systems affect the potential of implementation, since the increase in the expected cash inflows (net returns) will reduce the expected payback period of the SWP systems and enhance the bankability of the landholders accordingly.



This is clear from the simple calculations in Table 6.1 for selected crops with higher expected net returns (MoALR, 2016).

**Table 6.1:** Selected crops of highest net returns per year for different cultivated areas (2014/2015)

| Crops of high net returns | Net Returns | 1 feddan | 2-3 feddans | 4-5 feddans | 6-7 feddans | 8-10 feddans |
|---|---|---|---|---|---|---|
| Dry Onion | EGP 10,815 | $1,405 | $4,214 | $7,023 | $9,832 | $14,045 |
| Garlic | EGP 10,316 | $1,340 | $4,019 | $6,699 | $9,378 | $13,397 |
| Clover | EGP 11,924 | $1,549 | $4,646 | $7,743 | $10,840 | $15,486 |
| Aniseed | EGP 9,307 | $1,209 | $3,626 | $6,044 | $8,461 | $12,087 |
| Marjoram | EGP 14,670 | $1,905 | $5,716 | $9,526 | $13,336 | $19,052 |
| Pepper | EGP 6,597 | $857 | $2,570 | $4,284 | $5,997 | $8,568 |
| Eggplant | EGP 13,470 | $1,749 | $5,248 | $8,747 | $12,245 | $17,494 |

It can be easily deduced that the more the cultivated area with these crops, the higher the expected cash inflow, accordingly the more bankable the landholder would be perceived and hence the easier the implementation of the SWP systems.

For a system of average capacity 6 kW for solar PV panels and 6 hp for pump, the estimated cost is around USD 7,000. Therefore, to have a reasonable payback period not exceeding five years, SWP systems are feasible for any cultivated crop with a minimum annual net return of around USD 1,400. Moreover, for a smaller SWP system (5 kW), the cost is relatively lower (~EGP 50,000, USD 2,820) and accordingly the expected payback period will be shorter. This could be ideally suitable for surface water irrigation.

## 6.4 Market Growth towards Strategic Goals (2022 - 2035)

The only announced strategies are those of the MoERE, for the share of RE applications to reach 20% by 2022 and 37% by 2035. These encompass all different types of RE technologies (hydropower, wind power and solar power).

It is targeted for the distributed solar PV installations to reach 300 MV by 2020. If this very conservative estimation was applied, the achievement of this target should be granted. The idea that around 100 MW could be installed annually for SWP systems shall contribute considerably to the strategic target with 1.8 GW by 2035, based on these simple and very conservative estimations.

However, in reality these estimations could be easily exceeded due to the high potential discussed earlier, especially if certain supportive measures are considered for upscaling the SWP market.

## 6.5 Possible Realistic Scenarios

Moving to a more realistic approach, we will consider the total number of pumps already available in the market (957,534 pumps) and link the capacity of installations to the planned targets for the years 2022, 2035 and beyond. For each year starting 2017, only 1% is assumed to switch to SWP (~9,575 pumps), each SWP system is of an average size of 20 kWp, for the market price of USD 22,535 each (as of May 2017). The expected results are summarized in Figure 6.6.

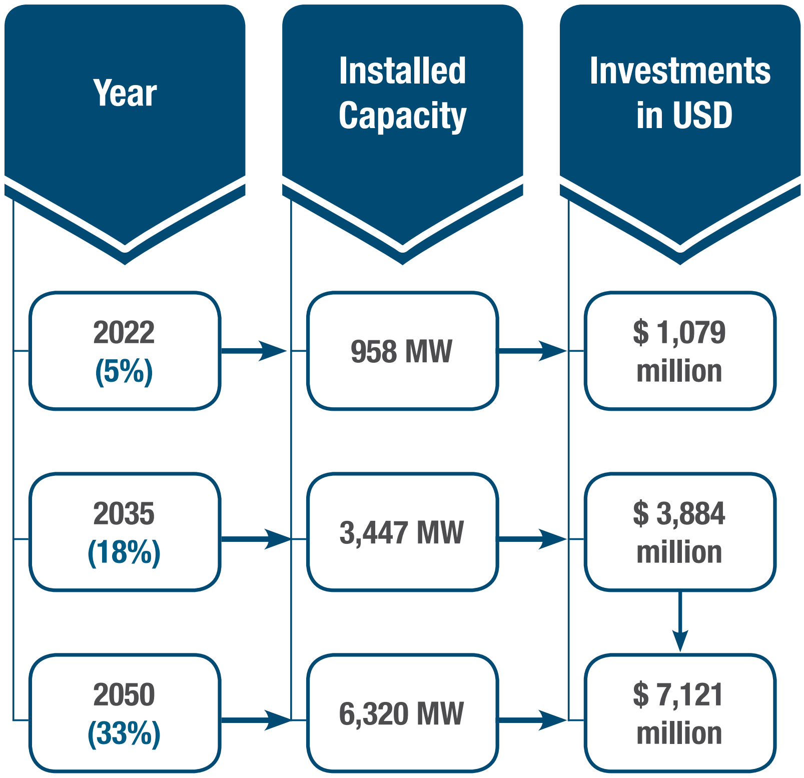



**Figure 6.6:** Possible realistic scenarios for 2022, 2035 and 2050

These scenarios are rather modest, knowing that the announced national renewable energy targets in Egypt are 20% by 2022 and 37% by 2035 of the electricity generation. Unfortunately, these targets seem not to consider the high potential for solar pumping applications, since it addresses mainly the power sector. Nevertheless, if SWP would go in harmony with such national targets, the scenario for 2050 mentioned above would be achievable in a shorter time (e.g. 2035). This will accordingly translate into higher local value and more jobs could be created based on this acceleration. Applying the outcomes of the analysis in section 6.3 would result in creating annual jobs of around 879 man-year (jobs) for the 192 MW installations (total installed capacity for one year), and at least 1,450 jobs for O&M over the expected lifetime of the installed SWP system (6,320 MW) through converting 33% of the existing diesel pumps into SWP systems.

It is important to highlight the fact that these scenarios are based only on replacing the existing diesel pumps. There is also considerable potential for new SWP systems' installations due to the new national project for reclamation of the three million feddans, in addition to other individual projects in remote areas like the deserts and oases. Besides, with the growing market for solar PV technologies, the respective amounts for investments are expected to decrease over time due to the economies of scale, resulting in an overall decrease in the international prices for this technology.

# Main Outcomes and Findings

# 7 Main Outcomes and Findings

It is obvious that there is already an existing market for SWP systems and it is growing on all levels, individual and business landholders, as well as government authorities. The investigations revealed a rough estimation of already installed capacity of 40 MW in the market, with around 20 companies operating in supplies, installation and maintenance, mostly in the Oases and Western deserts. Each of these companies installed a number of SWP systems between 50 and 100 systems over the last few years; the average size of these SWP systems is around 20 kW. This could be attributable to different factors: (1) unstable prices for diesel, (2) uplifting the subsidies on diesel (since 2015), (3) lack of diesel supply, especially in remote areas.

However, since applications in this market are not mature enough, it is advisable to be flexible in designing the irrigation systems, considering system optimization as an initial step towards upscaling SWP applications. There are successful applications based on the underground water in some new communities (especially in the western desert and Oases), where hybrid irrigation systems are optimized, in order to balance the systems' cost with system robustness, as well as maximizing the overall system efficiency. This compromise is also applicable where several wells could be connected to centralized generator driven with solar PV system. Hence, promoting SWP does not necessarily mean relying solely on solar energy.

The fact that the GoE (represented by the MoWRI) is "leading by example" is extremely important; not only for promoting SWP systems, but also for identifying the areas which require more attention and where the real challenges are, and how to better address these challenges based on practical experience. In fact, since the MoWRI is one of the main key stakeholders in the market, it could introduce success stories for surface irrigation, following the same pattern of the new national project using underground water (government wells). In this regard, the MoWRI could launch a pilot project for partially operating the large capacity pumping stations with solar PV panel, through using the canals itself as the installation sites (covering canal closer to the premises). If this pilot project is proved to be successful, it could be implemented in phases to different pumping stations along the Nile River. This is one of the biggest untapped potential market segments for SWP applications in Egypt.

In addition to flexibility, innovative solutions are highly required, both on the technical and business-model levels and also on the incentives and supporting mechanisms. There are many success stories that could be adopted and customized to suit the application in Egypt. This can be useful, especially in addressing the challenge of fragmentation in landholdings especially in the Nile valley and delta. The analysis showed that there are already 210,010 portable pumps of capacity less than 5 hp (~22% of total pumps). Since the surface water is the main source for irrigation and it available at depth not exceeding two meters in the canals, mobile SWP (~4 – 5 kW) could be used instead. Hence, replicating the successful implementation in Kenya, where these mobile SWP are used for sprinkler irrigation, as displayed in Figure 7.1 (KAVES, 2017).

**Figure 7.1:** Portable and mobile SWP in Kenya

Despite the fact that a very conservative model was applied in calculating the socio-economic impacts for the SWP applications, relying on the bottom-up approach based on real cases for implementations produced reasonable results. For instance, the calculated employment factor for SWP systems was found to be 4.59 man-years (i.e. jobs) per MW installed. These jobs are either direct or indirect jobs, with the potential of extending this model to cover many other services and activities promoting the local value chain, once the respective numbers are available. The estimated jobs to be created yearly are 459 jobs, for an installed capacity of 100 MW of SWP systems, which reflects the conversion of less than 1% of available diesel pumps currently in operation. Accordingly, these outcomes add more reasons for giving more attention to boosting the SWP application in the agriculture sector for Egypt, both in the old and new lands, for surface and underground water.

## 7.1 Main Recommendations and Suggestions

For an optimized solution contributing to water sustainability, energy efficiency and food security, certain main aspects are considered crucial and should work in parallel and in integrated way. The following points shall summarize and highlight the recommended measures to consider for upscaling the SWP applications:

### 7.1.1 Enhanced Policy and Regulatory Framework

1. **Sustainable use of water:** It requires minimizing the losses and efficient use of available resources.
    a. **For surface irrigation:** losses during irrigation process were reported to be 40% in the minor canals or marwas (AfDB, 2014). Therefore, integrated water resource and irrigation management should be applied.
    b. **For underground irrigation:** close monitoring systems need to be applied on all existing wells, existing laws must be enforced, and any violations must be subject to reasonable penalties.

2. **Inter-ministerial collaboration:** since the topic is multi-sectoral, it requires close cooperation between the main participating ministries (MoWRI and MoALR on one hand and MoERE and MoNRP on the other hand), especially with regards to:

   a. **Cropping pattern:** the MoALR and MoWRI should cooperate in designing cropping patterns which support water sustainability and is also suitable for the new reclaimed areas.

   b. **Non-Financial incentives:** could be through encouraging the cultivation of high value crops to promote the installation of SWP systems.

   c. **Creating new markets:** locally and internationally to support crops' cultivation using green technology, where exports' incentives could be applied to promote SWP installations.

   d. **Other measures:** any innovative practice that would contribute to efficient and sustainable use of water must be encouraged by the respective governmental bodies and entitle the farms for extra benefits or incentives (for example using greenhouse for cultivation minimize water losses).

   e. **Introducing** a "smart subsidy program" for installations might be an option for SWP applications, especially for small scale farmers (as in Tunisia).

3. **Technical assistance:** goes in two main folds:

   a. In general, for all governmental bodies and employees involved policy making related to SWP in specific and sustainable and efficient use of water in general. These government officials must be better equipped to design, set and apply adequate policy and regulatory framework necessary to promote SWP market.

   b. In specific for the MoWRI to sponsor and/or offer technical assistance in evaluating SWP systems, to ensure that adequate capacity is installed for the cultivated crops, to maintain a sustainable withdrawal rate from underground water. The support of development partners would be of great added value during the initial phases of deployment.

4. **Qualifying installers:** following the same process adopted by the MoERE to qualify installers for solar PV solution to be connected to the grid, the MoWRI could also initiate a quality certification scheme for all SWP systems available in the market in collaboration with the MoERE. The purpose of such scheme is to protect the end users (farmers and landholders) and to avoid spreading the negative reputation due to poor quality and less efficient products especially that around 15 to 20% of the performance failure is due to quality issues. Among the necessary measures to consider in this scheme to qualify the SWP installers are the following:

   a. Clear and transparent process to qualify and approve SWP installations, as well as regular audit on the installed systems to ensure sustainability of groundwater resources.

   b. Sharing the list of pre-approved SWP suppliers through MoWRI (and NREA for the solar PV) to increase the confidence of the end users in the installed SWP systems.

   c. Prepare and publish guidelines for SWP installers as a reference for the designs suitable for selective crops, and guidelines for farmers suggesting convenient SWP systems to meet their needs.

### 7.1.2 Raising Awareness and Capacity Building

The investigations for this study disclosed the missing role of important stakeholders in the farmers' community. For many years, the roles of the Farmers' Union (FUs) and Farmers Associations (FAs) and cooperatives have been limited to agriculture related issues, like availability and quantity of subsidized fertilizers, legalization of land rental, etc. With the recent developments in the market, it is now crucial to empower these entities (FUs and FAs) to assume leading, more active and market-driven role to cope with these changes.

In fact, the proposed model in the new national project (1.5 million feddans) is inspiring and could be replicated and adopted to tackle the problem of fragmentation of landholdings, where the FUs and FAs are required to play a leading role, bringing micro and small scale farmers together under one umbrella. The holdings of each farmer could be translated into "share equivalent", building up a "farmers' shareholding" within a certain district, hence enhancing the farmers' sense of responsibility and ownership towards "group" rather than "individual".

To put this recommendation into practice, the persons in charge in the respective FUs and FAs will need specialized capacity building. Also the farmers will need tailor-made campaigns to raise their awareness to related issues (like efficient use of water, sustainable management of water resources, importance and impact of SWP applications, how to better finance these SWP systems, availability of loans, etc.). In addition, the FUs and FAs could also act as financing intermediaries between the financial institutions (banks) and the micro and small farmers, in case they have a proven record of financial credibility.

Raising awareness includes also promoting successful examples and initiatives in small communities, such as the revolving funds for operation and maintenance expenses of SWP systems adopted in Eldakhla oasis, as well as promoting shared responsibility among all beneficiaries.

Conducted inspection of more than one GW solar PV installations showed that around 50% of the defects in individual segments are caused by and related to installation of the solar PV systems (TÜV, 2013). Also, field's insights indicated that around 15 to 20% of the performance failure is due to quality issues, which affects the crops' yield and increase the overall cost of installed SWP systems. Therefore, specialized qualification schemes and capacity building are required to secure the availability of highly skilled labour force for more reliable installations and maintenance, this includes:

a. **Suppliers and installers:** to enhance the planning and designing skills to ensure that actual production matches the required production and hence efficient use of money, water yield.

b. **Technicians and electricians:** to offer high quality service, through vocational training courses based on internationally acknowledged standards for installation and maintenance of small, medium and large scale installations.

Capacity building is also essentials for other participants and stakeholders to promote SWP market, including:

c. **Financial institutions and financiers:** to have better understanding of the technology and real market needs, in order to enhance their capability to design and tailor-make innovative financial mechanism and facilities required to satisfy the market needs, especially for micro and small farmers.

### 7.1.3 Qualified Supply Chain and Innovative Financial Mechanism

The quality of the main components of SWP systems is very important factor, which implies the following conditions need to be considered:

a. Agreed product standards, testing and certification of products available in the market are important instruments to mitigate technical risks.

b. Adoption of monitoring systems for effective management and control of the intermittency and variability factors related to SWP (together with efficient design for required capacity)

In addition, availability of funds and adequate financial mechanism are driving factors for promoting the local market. Accordingly, financial institutions need carry out detailed research to have better understand of the real market needs, in order to offer financial packages for different participants with adequate and affordable terms. This could be:

c. Dedicated credit lines with guaranty facility for micro and small farmers

d. Adequate financial facilities to the suppliers of SWP systems (suppliers' loans)

## 7.2 Conclusions

It is clear that the potential of applying SWP for new land reclamation is big and the overall framework conditions seems to be ready for application. However, in order to boost the SWP market and to achieve a profound impact, the potential in the Nile valley and delta should be given more attention, especially that old and inefficient pumps could be replaced by SWP systems, if reasonable incentives and reliable information are well communicated to the target groups.

The application of SWP solutions is an ideal solution as far as the sustainability of river-based irrigation and underground water reserves are concerned. Typically, SWP is coupled with modernizing the associated irrigation systems, which would be of great value to the development of the traditional agricultural sector in Egypt. Furthermore, SWP would help replacing the old inefficient pumps, representing more than 40% of the operational irrigation pumping fleet, which would substantially improve the irrigation system efficiency, particularly in the old land around the Nile. Moreover, the main and common disadvantage of SWP related to the limited hours of daily operations (during sun shine) is the main guarantee and natural security factor needed to control the discharge and withdrawal rates from the underground water wells, insuring its sustainability and that the withdrawal rates by SWP are within the safe pumping rate identified by MoWRI and therefore increasing the lifetime of the wells itself.

Furthermore, the application of SWP systems contribute to creating local value and job creations, as well as to the announced strategies for increase the share of RE applications. Appling a very conservative model and considering the simplest assumption of converting only 1% of total 500,000 pumps from diesel to SWP system showed results that SWP systems of total capacity of 100 MW could be installed annually, creating around 459 jobs per year. In addition, resorting to SWP would help considering the switch towards the cultivation of high value crops, which is proved to have a positive impact on the expected cash inflow, and accordingly enhances the bankability of the landholders to finance the SWP systems.

The results of this market assessment, although very conservative, are based on real inputs, recently announced numbers and robust calculations. Therefore, it is recommended to consider these results as reliable initial indicators, on which further in-depth studies and business models could be generated to support the water energy and food nexus in Egypt and further applications of SWP systems for different feasible scenarios.

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