***Renewable Energy & Water Pumping: the basis for a Nexus Approach to Agricultural Development***

This paper aims to highlight renewable energy's role in improving water governance, tackling climate change, and facilitating sustainable agricultural development for food production in the MENA region. A case study of the activities of KarmSolar, a Cairo-based Solar Technology Provider, demonstrates the relevance of solar energy system integration into these important spheres.

In off-grid desert locations, water extraction is the primary stage of the agricultural process. KarmSolar's development and operation of High-Capacity Off-Grid Battery-Free Solar Water Pumping ("SWP") systems places them as an important actor in 1) the cost of the supply of water (which is directly affected by energy costs incurred by running pumping systems), 2) groundwater withdrawal rates, and 3) the administration of aquifer and climate data (through the use of the Solar Management Interface – "SMI").

To comprehensively tackle the water-energy-food nexus and climate change debate, the off-grid agricultural sector's water management regime, which begins with the extraction of water from underground aquifer systems, must be addressed. KarmSolar's development and operation of the SWP system must be given prominence within the discourse due to the direct social and economic effect it has on participants and stakeholders within the agricultural sector, but also the environment and the natural resources on which we all rely.

This paper's contents are as follows:

## 1/ KarmSolar introduction

Established in 2011, KarmSolar is an Egyptian Solar Technology Provider that offers complete EPC services. KarmSolar develops solar technologies (both hardware and software) that target water pumping and irrigation systems; such as pivot, drip and sprinklers; converting them from running on diesel generators for electric power to solar photovoltaic systems. KarmSolar is Egypt's largest and fastest-growing private off-grid solar integrator with 28 full-time employees and, at the time of publishing, 1.6MW of installed and contracted solar capacity for 34 solar water pumping systems.

*

The activity of KarmSolar has been expanded to cater to rising demands and exploit increasing opportunities for solar integration for the Industrial, Tourism, and Residential sectors, expanding its vision far beyond agriculture. The KarmSolar Group includes: *KarmSolar*, specialising in innovative hardware and software development, project development and EPC project management; *KarmBuild*, delivering architectural designs, solar infrastructure, construction management and project development; *KarmPower*, focusing on Energy Management Services and utility-scale solar power plants through Power Purchase Agreements and lastly; *KarmTrading*, which caters to the group's procurement needs. The KarmSolar Group's vertically-integrated business model allows them to offer a full range of solutions to their clients by providing consultation, design, EPC, procurement, and after-sales services ensuring efficiency, high quality delivery, and operation.

**

After winning 1st place in the HCT-Wharton Innovation Award for the *Off-Grid High-Capacity Battery-Free Solar Water Pumping Solution* in 2012, the solution was implemented as a commercial pilot project for an agribusiness in the Bahareya Oasis in 2013. The conversion of the client's existing pump from relying on diesel to solar energy was the MENA region's first high-capacity battery-free solar water pumping system.

As KarmSolar is heavily focused on innovation and value-addition to their products, they built the KarmSolar Research & Development Laboratory in close vicinity to the pump, allowing optimization of the product and the development of further cost-effective and applicable solar technologies. This is KarmSolar's second office, acting not just as an R&D facility but also an operational headquarters for their projects in Egypt's Western Desert. Complete energy independence is achieved with a 7.5kW solar array and the structure is built using locally-sourced natural earth materials with passive design features; *Solar-Integrated Earth Construction* is the pioneering building typology of KarmBuild.

## 2/ The SWP System & SMI Product Descriptions

The High-Capacity Battery-Free Off-Grid Solar Water Pumping System, which won 1st place in the HTC-Wharton Innovation Award in 2013, is a patented turnkey standalone solution that is designed to be implemented on the user's existing pump, replacing its diesel-powered energy infrastructure with solar, the system is easily applicable in energy-constrained (off-grid) environments. The solution can be applied to most submersible motor pumps that reach up to 600 HP and Grundfos Egypt recommends the use of KarmSolar's solutions with their pumps. Grundfos is the world's largest pump manufacturer.

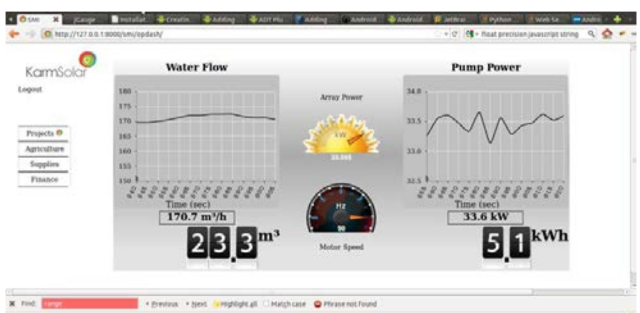
Each installation of the system is fully-integrated and custom designed to adapt to the power needs of the specific pump and the user's water requirements, yet can be scaled up to meet changing energy demands; enabling the lifting of water at increasing depths, adapting to well draw-down.

KarmSolar provides system support throughout the solution's 25-year lifetime including performance checks and maintenance training, the operation and maintenance needs are minimal in comparison to diesel generators, it is noise and pollution free and with every installation the user has access to the Solar Management Interface.

*

The Solar Management Interface (SMI) is a comprehensive web-based management system for solar system design, construction and operation that is in its third year of development. The SMI simplifies and supports the user's decision-making by providing relevant visuals and real-time statistics such as irrigation schedule, crop profile, supply and demand curve etc. The scalable sensor-systems allow the SMI's use from small-scale electrification systems to full-scale irrigation infrastructure for commercial farms and more.

The SMI's pumping-specific applications are as follows: it allows the user to monitor the pumping system from a remote location; giving access to data indicating the amount of water being produced at any point in time and providing alerts of any failures. In addition, it monitors critical system parameters such as; solar insolation, water level in the lake, temperature of the pump motor, flow rate, etc. for continuous optimization of the system performance. It also executes corrective/preventive actions in the case of system underperformance or alarm signals; i.e. if the pump overheats the system disconnects, therefore preventing motor-damage and prolonging the pump and solar system's lifetime.




**3/ The SWP system & SMI's Advantages within the Agricultural Sector**

KarmSolar's SWP system holds several advantages over conventional systems commonly used in the region: the majority of water pumps in Egypt and MENA depend on diesel fuel; solar technology's maturation and declining costs has now made the use of solar power the most economical choice for off-grid agriculture. SWP has become a widely adopted solar energy technology in the last two decades with over 10,000 PV water pumping systems installed worldwide up to the year 1993. This figure grew to over sixty thousand systems by 1998.

However, while these systems already existed in MENA countries such as Bahrain, Egypt, Iraq, Jordan, Oman, Palestine, Syria and Sudan, they were of a small capacity, only being able to operate motor pumps up to 6kW. These pumps are too small to facilitate access to the deep aquifers located in the major off-grid reclaimed agricultural areas of Egypt. In addition, the sites at which these aquifers are accessible are very far from both the electricity grid and diesel services.

In addition to these energy challenges limiting the expansion of agriculture into desert lands, there have been other factors such as underdeveloped technologies and prohibitive costs. In the past few years these factors have changed, unlocking the potential of these areas for development. While there are 490 million acres of agricultural land in the MENA region, these countries have varying degrees of electricity grid coverage. In Egypt, it has been found that there are 2.2 million acres of off-grid desert land with potential access to groundwater, providing ample room for the agricultural sector's expansion. Recent announcements made by the Egyptian government have indicated that a further 1 million feddans of off-grid land will be reclaimed for agricultural use in areas such as Toshka, East Oweinat, and the New Valley Oases (Bahareya, Farafra, Dakhla and Kharga), from which KarmSolar estimates a potential market of 80MW of SWP potential.

*

The use of the SMI with the SWP system is optional, yet the ability to remotely monitor the system gives the user a level of system control that indicates that it will be used with the majority of pumping systems that KarmSolar installs. The SMI adheres to the maximum flow rate yield prescribed by the Ministry of Water Resources and Irrigation and the Groundwater Sector, limiting the ability of the farmer to over-pump, prolonging the life of the well and aiding sustainable water extraction. The SMI's monitoring of water extraction rates allows for the collection of useful water extraction data. As the SMI is further disseminated this database will continue to grow, providing a rich source of information which can be applied to aid decision making on a local, national and regional scale. As mentioned previously, the SMI's applications are numerous and as KarmSolar's services expand; the technology is being further developed to add value to their range of services.

**4/ Key Factors catalyzing the shift to Solar Energy**

KarmSolar was able to penetrate the energy market by: targeting off-grid locations where solar systems present an economically feasible and attractive option for a user in comparison to diesel-run irrigation infrastructures, bypassing the market obstacle of high competition from fuel subsidies, providing a context-specific solution by taking advantage of an abundant natural resource, and developing a relevant product in a time of severe national strategic need to increase sustainable and efficient agricultural production.

As discussed, in remote agricultural areas energy insecurity is widespread, stemming from factors such as: lack of access to the local grid, unreliable supply of fuels due to shortages and an excess in demand, and even black market activities blocking fair access. Energy insecurity threatens an agribusiness's ability to produce and be profitable; in addition to the constant threat of being unable to lift water for irrigation, leading to a lost harvest after sometimes just three days due to the harsh desert climate, an insufficient energy supply forces agribusinesses to limit their production capacity, leaving large tracts of land uncultivated and causing seemingly profitable land investments to fall far short of their potential. This grouping of issues made the agricultural sector, in this case large commercial farms based in reclaimed desert lands, an excellent opportunity to begin the commercial use of solar in Egypt.

In these environments, the competition of fuel subsidies was reduced. While being a key political tool for the government, subsidies have a significant economic consequence such as distorting energy markets and acting as an obstacle to the development of alternative energy resources (among many other issues that will not be discussed here). In 1990 (May) the diesel price was EGP0.09 per liter, rising to 0.36 in 1993 (July) when it remained unchanged for almost a decade. In 2011, the price for diesel stood at EGP 1.1 per litre, one eighth of the world market price; however, subsidy reforms in 2014 caused the diesel price to rise to EGP1.8 per litre, further increasing the system's cost-competitiveness with diesel generators for the application of off-grid water pumping.

Egypt is one of the Solar Sunbelt nations, a geographical clustering of countries that lie on or near the equator where solar irradiation is at its highest. This abundant resource has failed to be exploited until now with traditional fossil fuels like oil, gas and more recently coal, still representing the major components of the nation's energy mix. However, the Egyptian government has begun to support its spread through asserting that it will be a component of upcoming housing and agricultural projects. In addition, greater grid-connected penetration of solar will be facilitated through a Feed-in-Tariff system. This pragmatic acceptance that Egypt must incorporate renewable energy in new developments and increase process efficiency by converting existing energy infrastructures shows promise for the country's ability to satisfy the rising electricity demand.

## 5/ SWP Pilot Project: Financial and Socio-Economic Benefits

*Disclaimer: Since the report was compiled there has been an increase in the diesel price and the system cost has been significantly reduced, the figures used for the financial analyses are now out of date therefore the reader must assume that the cost-efficiency of the SWP has increased further.*

SWP Pilot Project: the conversion of an agribusiness's submersible water pump from relying on diesel generators for the production of electricity to a solar energy system.

An indicator of the farmer's confidence in the system is that due to its high efficiency and reliability, he completely removed the replaced diesel generator from the vicinity of the pump after just three weeks of the SWP system's operation. Moreover, the SWP system's achieved a higher flow-rate than the diesel-run system during peak hours of operation, indicating increased pumping efficiency, maximizing the cost effectiveness of the pump's initial purchase. Operational security was also boosted due to built-in failure prevention system supported by the motor temperature sensors that predict pump failure

Location: Tayebat Farm, Bahareya Oasis, Giza, Egypt. Coordinates: 28.38 N, 28.9 E

| **Well Details** | | **Pump** | | **Energy Generation** | | **Electrical information** | |
|---|---|---|---|---|---|---|---|
| Static Head | 12m | Manufacturer | Grundfos | Solar array size | 50 KW | Maximum input | DC voltage: 815 VDC |
| Total Head | 35m (to lake) | Model | SP 125-3N | Solar panel rating: | 250 Wp | Voltage output | 380 VAC |
| Maximum flow rate | 165m3/hr | Capacity | 30 KW/ app. 40 HP | Efficiency: | 15.6 % | Maximum Current | 100 Amp |
| Hours of operation | 10 hours/day Average throughout the year | | | Tilt angle: | 25 degrees (optimum for year round yield) | Frequency operation range | 30 -50 Hz |

A Cost-Benefit Analysis of the pilot project was undertaken by a cohort of masters students in the Development Planning and Policy Analysis Class of the University of Michigan's Humphrey School of Public Affairs, under the guidance of Professor Ragui Assaad, over the course of four months in the beginning of 2014.[1] The analysis assesses the profitability of the SWP system, undertakes a social cost-benefit analysis, and also identifies a number of other social benefits to be gained from the system's uptake in the agricultural sector.

*

Financial benefits:

In conducting an assessment of the pilot project's private profitability, a number of sensitivity analyses were taken into account such as changing economic conditions, component costs, project discount rate, the diesel price and non-diesel operating costs of the diesel generator and the solar systems. It was assumed that to ensure reliable access to subsidized diesel, the farmer had to pay a black market premium of EGP 0.9 per liter on top of the official market

[1] Statistics and analyses in this chapter are taken from the following paper: Cost Benefit Analysis of Converting Off-Grid Irrigation from Diesel Power to Solar Power: *Implications for Energy policy in Egypt.* The Spring PA 5521, Development Planning and Policy Analysis Class, Humphrey School of Public Affairs, University of Minnesota. Under the direction of Professor Ragui Assaad, 20th May 2014.

price of EGP 1.1(the official diesel price in august 2014). The analysis covered a 20 year period, despite the system lifetime's being 25 years.

The analysis found that the most impactful variables on the project's personal profitability was the diesel price and changes in the non-diesel operating costs of the generator, rather than changes in operating costs of the solar system.

Based on the range of assumptions provided by KarmSolar of the farm's operations it was found that although the upfront cost of the solar solution is higher than that of a diesel generator, the operating costs of the solar solution is lower, allowing the farm to achieve a 20% saving rate over a five (5) year period and recoup its investment after 3 years by implementing KarmSolar's SWP system. This payback is calculated based on the diesel price in Egypt in Q2 of 2014 diesel (US$ 0.24 / liter, or EGP 1.65 / liter), a 50% premium above the official diesel price.

It was found that if farmers were to pay the international price of diesel (EGP 9.00 at the time of publishing); the rate of return on investment in the solar system would be 47% with a payback period of 2.1 years. An increase in diesel price to EGP 5.00 resulted in an IRR of 28% with a 3.6 years payback period. Even if the farmer were to pay the official price of EGP1.1 per liter, the IRR would still be positive at 8% with a payback period of 12.3 years.

Project Performance Indicators:

| **Indicator** | **Value** |
|---|---|
| Net Present Value (NPV) | US $159,163 |
| Benefit Cost Ratio (BCR) | 1.74 |
| Internal Rate of Return (IRR) | 13.2% |
| Payback Period | 7.6 years |

**

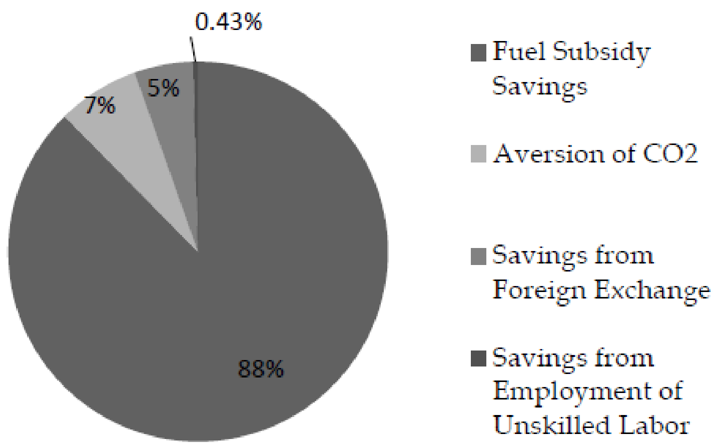
Socio-Economic benefits:

In addition to the financial benefits achieved by the conversion of pumping systems to solar energy, there are economic factors at play such as; mitigating crop loss caused by a vulnerability to fuel supply shortages, eliminating the exposure to fluctuating black market fuel prices, and the avoidance of $CO^2$ capture costs.

The analysis included a Social Cost-Benefit Analysis (SCBA) which evaluated the benefits society can obtain from the project by converting market prices of project components into their shadow prices i.e., their true, undistorted value to society. The deviation between net social benefits and net private benefits resulted from four main reasons: i) fiscal savings due to the government's reduced diesel subsidy burden, ii) the prevention of environmentally harmful CO2 emissions, iii) savings of scarce foreign exchange, and iv) benefits from employing abundant unskilled labor. Because the conversion to solar does not need a great deal of unskilled labor, we expect the latter component to be negligible.

It was found that the investment of $145,000 on the farmer's part for the SWP system that the net benefit returns to society are just under a million dollars, this is reflected in money saved by the government from the diesel that would be consumed over a 20 year period by a diesel-reliant pump. The government savings represent $665,000 (88%), the prevention of co2 emissions accounts for nearly $53,000 (7%)[2]. Savings on foreign exchange constitute a smaller amount of about 5% of the total net societal benefits, while savings from the employment of unskilled labour contributes a negligible amount.

Total Societal Benefit Breakdown chart:




***

In addition to the economic and financial benefits discussed above, there is also a wide range of social benefits which will affect users not only from among the large agribusiness bracket that employs hundreds of workers, but also small farmers whose livelihood depends on reliable production. The social benefits can be grouped into three areas: direct benefits for the farm and its workers, the benefits for the communities surrounding the farm and the social benefits on a national level. Increased application of the solution will serve to multiply these effects.

On the farm:

- Reliable and stable production causes better social conditions and opportunities for farm workers.

---

[2] This calculation is based on the value of each ton of averted $CO^2$ as benefiting society at $30/ton

- Introduction to environmental issues. Educating those in the agricultural sector about the opportunities provided by clean energy and how environmentally-friendly solutions can help to promote sustainable agricultural operations.
- Lowering $CO_2$ emissions- KarmSolar aims to remove the use of diesel completely in their targeted sectors. KarmSolar's pilot project alone saved 64,800 litres of diesel a year that would have produced 171,180 KG of $CO_2$ emissions.
- Increased local knowledge of agricultural conditions (based on data provided by the SMI) will help to develop practices that boost investor confidence in the farm and surrounding markets. The pilot project has been operational for almost two years, building extensive databases of various climatic and water-extraction information.

Serving remote areas and providing data for research institutes:

- A more productive farm that does not take a large share of the diesel supply which could be allocated to other areas of high demand.
- Job diversification & skilled labour. KarmSolar has made use of the local community for construction and civil works. Workers on their projects are exposed to advanced technologies and are thus provided with specific skill set training, enabling them to adapt to changing market demands. For their green construction projects, KarmSolar subcontracted an Earth Construction Mason who was given the opportunity to revive his skills and train new workers in this neglected construction method.
- KarmSolar added c.EGP4,500,000 into the area's local economy through subcontracting work on pilot pumping project, R&D facility and the Workers Village project, and an additional 8 wells for conversion. Through further spread of KarmSolar's work, the growing portfolio of skills will continue to be disseminated amongst local workforces. Hence, contributing to the resilience increase of the communities in the vicinity.
- Partnering with various research and academic entities, raising awareness which can direct research towards, for example, improving water management systems. KarmSolar hosts around 15-30 visitors a month to showcase the solution as well as its benefits to various entities and students.

On a national level:

- Stable commodity prices will be promoted by the solar water pumping solution which will fundamentally decrease the vulnerability of low-income citizens to fluctuating food prices.
- Support or help reduce government energy subsidies by replacing subsidized diesel with solar energy. This help will decrease the national deficit, and free-up funds that can be allocated to other high-priorities issues such as health and education.
- The protection of groundwater resources through the development of water management system. The solution can already guarantee the pump operates within the maximum safety pumping yield as prescribed by the Ministry of Water Resources and Irrigation and the Groundwater Sector.

- Lowering $CO_2$ emissions - aiming to remove the use of diesel completely in their targeted sectors, with a view to not just helping the clients make an economical choice for their future operations, but also to reduce carbon emissions and protect the natural environment. According to the Netherlands Environmental Assessment Agency and the European Commission's Joint Research Centre, it was found that the increase in global carbon dioxide emissions slowed down in 2013 because of a shift towards renewable energy usage in the U.S.A, China and Europe. KarmSolar envisions this for Egypt.
- Increase the value of the export product through green-labelling schemes which creates a greater opportunity for more foreign currency to flow into Egypt.

## 5) Conclusion

This paper has aimed to highlight renewable energy's role in: improving water governance, tackling climate change, and facilitating sustainable agricultural development for food production in the MENA region.

The financial and socio-economic benefits achieved by KarmSolar's SWP system, as per the pilot project case study, show that the role solar technology can play in the cost of water extraction, the ability to monitor water withdrawal rates and the advantages this data can provide within overall water consumption figures, are essential components of a comprehensive regional water governance plan.

KarmSolar's SWP system development is timely, coinciding with increasing urgency to address the issues of the water-food-energy nexus. The company is developing innovative applicable solar hardwares and softwares that will not just benefit participants and stakeholders of the agricultural sector, but also the environment and the natural resources on which we all rely.

KarmSolar
كرم للطاقة الشمسية