Diesel to Solar Transformation

Accelerating Achievement of SDG 7 on Sustainable Energy

Assessing Untapped Solar Potential in Existing Off-grid Systems in the Arab Region

2016

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

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Acronyms

AC	Alternating Current
ADDS	Agence Djiboutienne de Développement Social
DC	Direct Current
DC	Distribution Company
EdD	Electricité de Djibouti
EEHC	Egyptian Electric Holding Company
EGP	Egyptian Pound
EgyptSEFF	Egypt Private Sector Sustainable Energy Finance Facility
EPC	Engineering, Procurement, and Construction
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GTU	Green Tourism Unit
GWh	Gigawatt Hour
HDI	Human Development Index
HFO	Heavy Fuel Oil
HP	Horsepower
IPP	Independent Power Producer
Ktoe	Kiloton Oil Equivalent
kVA	Kilovolt Ampere
kW	Kilowatt
kW_p	Kilowatt Peak
MW	Megawatt
MWh	Megawatt Hour
PC	Power Company
PV	Photovoltaic
RCREEE	Regional Center for Renewable Energy and Energy Efficiency
SDG	Sudanese Pound
SIHD	Société Internationale des Hydrocarbures de Djibouti
UAE	United Arab Emirates
UNDP	United Nations Development Programme
USD	United States Dollar
YER	Yemeni Rial

About

The Regional Center for Renewable Energy and Energy Efficiency (RCREEE) is an intergovernmental organization with diplomatic status that aims to enable and increase the adoption of renewable energy and energy efficiency practices in the Arab region. RCREEE partners with national governments, international organizations and private companies to initiate and lead clean energy policy dialogues, strategies and capacity development in order to increase Arab states' share of tomorrow's energy.

Through its solid alliance with the League of Arab States, RCREEE is committed to tackle each country's specific needs and objectives through collaborating with Arab policy makers, businesses, international organizations and academic communities in key work areas: capacity development and learning, policies and regulations, research and statistics, and technical assistance. The center is also involved in various local and regional projects and initiatives that are tailored to specific objectives.

Having today 17 Arab countries among its members, RCREEE strives to lead renewable energy and energy efficiency initiatives and expertise in all Arab states based on five core strategic impact areas: facts and figures, policies, people, institutions, and finance.

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UNDP works in over 177 countries and territories, helping to achieve sustainable development and finding low-emission, climate resilient solutions. UNDP is the UNs largest provider for country assistance in the area of climate change, with a portfolio of over $1.4 billion of projects helping partners develop policies, leadership skills, partnering abilities, institutional capabilities and building resilience of sustaineble development results.

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Foreword

There is a significant potential in the Arab region for introducing solar PV technologies into existing diesel-based off-grid systems. Estimating this potential and highlighting existing hanging fruit opportunities is important for governments, financial institutions, technology providers and other relevant stakeholders. The following report is an earnest attempt to shed light on the market potential in four Arab countries; Djibouti, Egypt, Sudan and Yemen. These countries have significant off-grid diesel usage for water pumping for irrigation. The information and analysis presented in this market assessment report is based on stakeholder consultation, review of existing literature and knowledge accumulated from interactions with market actors.

A clean energy developmental path in rural areas will not only contribute to food and water security in Arab countries, but will also create jobs, reduce environmental pollution, and improve the livelihood of rural populations throughout the region.

Dr. Ahmed Badr

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Executive summary

Energy insecurity constitutes one of the main obstacles to achieving equitable, sustainable and long-lasting development. Tens of millions of households and businesses in the Arab region suffer from low access to reliable energy services. Access to electricity is particularly challenging due to the weakness and unreliability of national power networks in many countries. Consequently, decentralized diesel-based technologies are often used to meet the energy needs of residential and productive sectors, such as agriculture, tourism and industry. Diesel technologies are used for lighting, irrigation and pumping, agro-processing, heating and cooling as well as powering domestic and industrial electrical appliances.

Since the turn of the century, dependence on diesel has become increasingly problematic for households, businesses and national economies due to diesel scarcity and rising costs. On the other hand, solar photovoltaic (PV) has undergone what can only be described as a unique experience curve. According to IRENA, prices of PV modules decreased 75% between 2009 and 2014. Furthermore, solar PV technologies have proved flexible and adaptable, allowing for highly decentralized applications and seamless integration into existing power generation and distribution systems in remote areas to create "hybrid solar/diesel" systems.

However, although these types of hybrid solutions may be the most efficient option from a market point of view, they remain an untapped opportunity due to a host of soft barriers, mostly relating to financing, management, business models, maintenance and sustainable operations (Alliance for Rural Electrification, 2011).

This report explores the market potential for introducing solar PV into existing off-grid diesel-based energy systems in Djibouti, Egypt, Sudan and Yemen[1]. In doing so, it identifies market segments and business applications, which show significant promise for profitable investment by the private sector through off-grid solar PV retrofitting projects. To ensure technical and economic feasibility, the report focuses on partial introduction of solar photovoltaic (PV) into diesel-based energy systems to create "hybrid systems." Ideally, this type of partial substitution is merely a stepping stone toward complete replacement of diesel generation. Recent advances in battery storage suggest that complete replacement may become a real possibility within the coming decade. The inclusion of other forms of renewable energy such as wind, biomass or hydro can also lead to complete substitution of diesel fuel. However, only retrofitted solar PV/diesel hybrid applications will be considered in this report.

The report focuses on four common diesel-intensive applications for off-grid areas in the Arab region. These applications are characterized by a steady, long-term electricity need that justifies the investment in long-term PV systems. The focus on these existing, income generating business applications increases the economic attractiveness of solar retrofitting projects, which in turn serves to draw the attention of private sector companies and financial institutions (Alliance for Rural Electrification, 2011). The target applications are:

1. ***Utility mini-grids***
2. ***Private mini-grids***
3. ***Single-activity applications***
4. ***Water pumping in agriculture***

The following table presents the estimated diesel consumption in the four diesel-intensive applications in Djibouti, Egypt, Sudan and Yemen:

Table 1 - Diesel consumption figures for the four countries (000s tonnes)

Category (000s tonnes)	Djibouti	Egypt	Sudan	Yemen	Total
Utility mini-grids	5	78	40	223	346
Private mini-grids	20	60	-	78	158
Single-activity applications	-	-	-	16	16
Water pumping in agriculture	0.7	3775	52	1,648	5,475.7
Total	25.7	3,915	92	1,965	**5,997.7**

1. The information for Yemen is mostly based on the situation before the outbreak of armed conflict in early 2015. This development should not prevent international organizations from integrating solar energy applications into their humanitarian assistance operations on the ground. In the long run, solar energy is a more resilient form of technology to withstand armed conflict.

The four target diesel-intensive applications can be retrofitted with various commercially-available solar systems depending on the energy load profile, grid connection and diesel dependency. Table 2 presents the estimated potential solar PV capacity for these applications in the four countries. This potential is etimated based on conservative assumptions and is likely to be significantly higher.

Table 2 - Potential PV peak capacity for the four countries (MW_p)

Category (MW_p)	Djibouti	Egypt	Sudan	Yemen	Total
Utility mini-grids	0.7	82	53	280	415.7
Private mini-grids	7	77	-	76	160
Single-activity applications	-	-	-	5	5
Water pumping in agriculture	0.5	1,938	101	894	2,933.5
Total	8.2	2,097	154	1,255	**3,514.2**

This study has identified three main impediments to wide-scale deployment of decentralized off-grid solar PV technologies: (1) low awareness, (2) insufficient implementation capacity and (3) perception of high risk. Taken together, these hurdles complicate access to finance and lead to an unfavorable market environment for solar PV retrofits in remote areas. Consultations with various market actors and stakeholders including end users, technical solution providers, government and public agencies, development organizations and financial institutions in the four countries confirmed the findings.

Understanding and targeting these barriers through a comprehensive, systematic intervention will unlock the significant potential of solar energy, open markets for clean, affordable and reliable energy and accelerate the transition to sustainable economic development in the Arab region.

This study has identified three broad categories of activities that can accelerate the creation and scaling up of solar retrofit markets in the four countries and throughout the Arab region: (1) Market assessments and awareness raising, (2) Capacity building and technical assistance and (3) implementation of pilot projects.

In order for these activities to yield the desired results, they should be carried out in an integrated manner and coordinated on a regional level in order to capitalize on regional synergies and economies of scale. A clean energy developmental path in rural areas will not only contribute to food and water security in Arab countries, but will also create jobs, reduce environmental pollution and improve the livelihood of rural populations throughout the region.

1 Background

Energy insecurity constitutes one of the main obstacles to achieving equitable, sustainable and long-lasting development. Tens of millions of households and businesses in the Arab region suffer from low access to reliable energy services. Access to electricity is particularly challenging due to the weakness and unreliability of national power networks in many countries. Consequently, decentralized diesel-based technologies are often used to meet the energy needs of residential and productive sectors, such as agriculture, tourism and industry. Diesel technologies are used for lighting, irrigation and pumping, agro-processing, heating and cooling as well as powering domestic and industrial electrical appliances.

Since the turn of the century, dependence on diesel fuel has become increasingly problematic for households, businesses and national economies due to diesel scarcity and rising costs. In 2012, international crude oil prices were up almost 500% from their year 2000 level. The increase in retail diesel price in the Arab region was even steeper due to national governments' commitment to phase out fuel subsidies. The average retail diesel fuel price in Arab countries more than tripled between 2000 and 2014. Excluding the Gulf countries, the average retail diesel fuel price almost quintupled during the same period. Even when the global oil prices declined in 2014, diesel prices to end users in many Arab countries continued to climb. The increase in energy costs has placed serious burdens on public and private accounts, leading to decreased economic competitiveness, inflation and lower standards of living for affected populations.

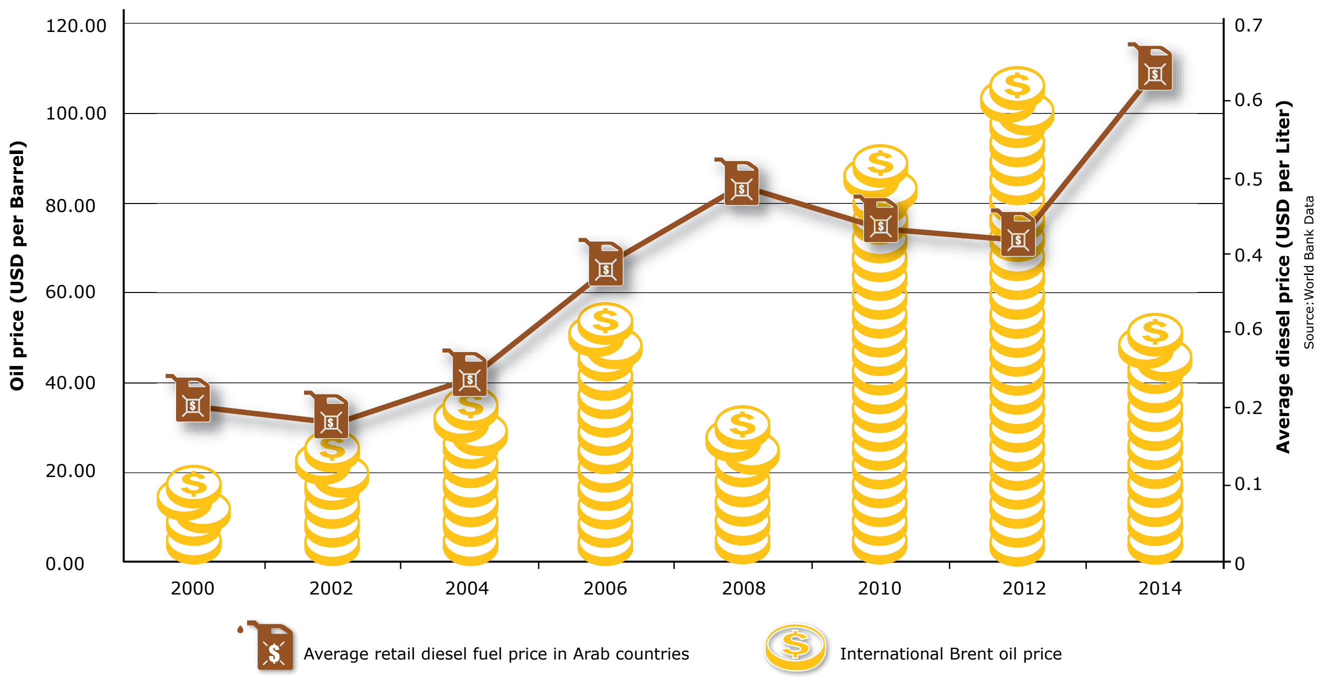


Figure 1 - International Brent prices and average diesel price in Arab countries

In recent years, access to diesel to operate generator sets (gensets) has also become increasingly unreliable in many Arab countries, especially in the context of political instability in the region. Growing shortage of diesel supplies poses significant risks to food, water and employment security. In Egypt, for example, where agriculture accounts for 15% of value-added in the economy and employs 54% of the population, the sector has been struggling to remain productive due to increased dependence on insecure and expensive diesel supply. The challenge is even bigger in Yemen, where about 70% of rural population depends on agriculture for its livelihood (ORSAM, 2015). Yemeni farmers have been struggling to maintain the sustainability of the agricultural sector due to increased cost and shortage of diesel supply. Diesel shortages in Yemen, even prior to the conflict, reportedly caused low-quality yields of pomegranates that resulted in a 50% revenue decrease for Yemeni pomegranate farmers.

Diesel generators in a Red Sea resort,
Marsa Alam, Egypt

Diesel gensets also expose local communities and workers to a plethora of environmental and health hazards, including noise pollution, noxious emissions and soil and water pollution. Furthermore, burning diesel to produce electricity contributes to global climate change by releasing significant amounts of carbon emissions into the atmosphere. In fact, each kilogram of burned diesel releases 3.2 kilograms of CO_2, making diesel electricity one of heaviest contributors to climate change per kWh produced.

As the cost of diesel continues to rise as a result of subsidy removal and access becomes increasingly unreliable, solar photovoltaic (PV) has undergone what can only be described as a unique experience curve. According to IRENA, prices of PV modules decreased 75% between 2009 and 2014. This development has led to a significant decline in the levelized cost of electricity for PV power, making it competitive in markets where diesel is sold at international prices (International Renewable Energy Agency). Furthermore, solar PV technologies have proved flexible and adaptable, allowing for highly decentralized applications and seamless integration into existing power generation and distribution systems in remote areas.

In fact, international experience from the past decade has shown that solar PV/diesel hybrid systems are the least-cost, long-term option for off-grid power generation in desert countries. This option is particularly attractive because a solar PV component may be integrated into the existing diesel-based power system to create a hybrid system. Solar panels provide a significant share of the needed power and existing diesel gensets consume less fuel. This retrofit lowers the overall capital cost of the solar PV project and eliminates the need for costly storage batteries.

However, although these types of hybrid solutions may be the most efficient options from a market point of view, they remain an untapped opportunity due to a host of soft barriers, mostly relating to financing, management, business models, maintenance and sustainable operations (Alliance for Rural Electrification, 2011). These factors include low awareness of the existence of these hybrid solutions, lack of well-publicized and successful pilot projects, weak local capacity for the development, implementation and operation of these retrofits and absence of appropriate financial instruments. Together, these factors lead to the persistence of the inefficient status quo and worsening energy insecurity in many areas in the Arab region.

Understanding and targeting these barriers through comprehensive, systematic interventions will unlock the significant potential of solar energy, open markets for clean, affordable and reliable energy, and accelerate the transition to sustainable economic development in the Arab region. A clean energy developmental path in rural areas will not only contribute to food and water security in Arab countries, but will also create jobs, reduce environmental pollution and improve the livelihood of rural populations throughout the region.

2 Regional market analysis and segmentation

2.1 Purpose and scope

This report explores the market potential for introducing solar PV into existing off-grid diesel-based energy systems in Djibouti, Egypt, Sudan and Yemen. In doing so, it identifies market segments and business applications that show significant promise for profitable investment by the private sector through off-grid solar PV retrofitting projects. To ensure technical and economic feasibility, the report focuses on partial introduction of solar photovoltaic (PV) into diesel-based energy systems to create "hybrid systems." Ideally, this type of partial substitution is merely a stepping stone toward complete replacement of diesel generation. Recent advances in battery storage suggest that complete replacement may become a real possibility within the coming decade. The inclusion of other forms of renewable energy such as wind, biomass or hydro can also lead to complete substitution of diesel fuel. However, only retrofitted solar PV/diesel hybrid applications will be considered in this report.

The report focuses on four common diesel-intensive applications in off-grid areas in the Arab region. These target applications are characterized by a steady, long-term electricity need that justifies the investment in long-term PV systems. Focusing on these existing, income-generating business applications increases the economic attractiveness of solar retrofitting projects, which in turn serves to draw the attention of private sector companies and financial institutions (Alliance for Rural Electrification, 2011). The target applications are:

1. ***Utility mini-grids***
2. ***Private mini-grids***
3. ***Single-activity applications***
4. ***Water pumping in agriculture***

The report does not explore diesel uses and solar retrofitting projects in single households as the focus of this study is on the use of energy for productive activities.

2.2 Target applications

This section provides an overview of the four target applications and their estimated potential in Djibouti, Egypt, Sudan and Yemen. More detailed information can be found in the country-specific chapters later in the report.

2.2.1 Utility mini-grids

Utility mini-grids are small, isolated electrical networks that are either owned and operated or leased by public utilities. They serve population centers and economic zones that cannot be connected to the central grids due to technical or financial challenges. Each mini-grid provides electricity to hundreds, or even thousands, of households and small businesses which otherwise would be deprived of electricity. In this particular application, the government-owned public utility supplies the fuel, maintains the electrical network and may collect fees from consumers to recover costs. Utility mini-grids require electricity during daytime and nighttime due to the fact that they serve a diverse mix of public, commercial and residential clients. Mini-grids in the Arab region are almost exclusively diesel-based with multiple diesel gensets feeding them with electricity.

This market assessment has found there are at least 58 utility mini-grids in Djibouti, Egypt, Sudan and Yemen that consume 346,000 tonnes of diesel and release over 1.1 million tonnes of CO_2 annually. Utility operators have reported many problems associated with securing the needed supply of diesel due to stock shortage, rising prices and logistical challenges related to fuel storage and transportation.

Diesel-based utility mini-grids can be retrofitted with solar PV components to reduce the reliance on diesel during daytime. Egypt has active solar hybridization projects for its isolated utility mini-grids. The other three countries have not yet planned or implemented strategies or initiatives in that respect, leaving this segment's potential largely untapped and opening the door to new projects and investment opportunities.

2.2.2 Private mini-grids

From a technical perspective, private mini-grids are the same as utility ones. In both applications, diesel gensets supply a local distribution network with electricity. The main difference resides in the end user profile. Private mini-grids serve a single (or a few) large enterprise(s) instead of multiple households and businesses. The single enterprise may be a resort, a port or an industrial facility. Private mini-grids are typically owned by the same enterprise, although in some instances the diesel gensets, and even the distribution network, may be owned and operated by an independent investor, what is commonly known as an independent power producer (IPP).

In preparing this report, concrete data about private mini-grids were available only for Egypt and Yemen, which have revealed significant off-grid diesel generation in private sector activities in the tourism and industrial sectors. These sectors can greatly benefit from solar energy retrofitting. Private electricity generation is estimated to consume around 158,000 tonnes of diesel and release over 400,000 tonnes of carbon emissions each year.

In Egypt, this potential is especially prevalent in the tourism sector. The Red Sea resort area of Marsa Alam and many beach resorts along the North Coast are entirely off-grid, with multiple luxury hotels and water desalination plants operating solely on diesel gensets. There are currently no plans to extend the central grid, indicating promising long-term prospects for solar retrofitting in Egypt's tourism sector.

Yemen's industrial sector is almost entirely dependent on diesel gensets for electricity due to the unreliability of or inaccessibility to grid supply. Considering the scarcity of quantitative data about Yemen's industrial sector, actual consumption is likely to be much higher than the estimate provided in this report.

Diesel-based mini-grids can be retrofitted with solar PV to create solar-diesel hybrid systems. Some resorts in Egypt have begun experimenting with this solution in recent years as a result of diesel supply shortages and the phasing out of fuel subsidies.

2.2.3 Single-activity applications

Single-activity applications are dedicated to serving one public, commercial or industrial activity usually with a relatively constant load profile and schedule. Examples include telecom base stations, construction site equipment, oil and gas extraction rigs, health clinics in refugee campsites and mining equipment. Unlike mini-grids, the diesel gensets in these applications are directly connected to the equipment without local distribution networks. With the exception of telecom base stations, single-activity diesel gensets require a degree of mobility to be transported with the attached equipment within the site or to another site.

Quantitative data about single-activity electricity generation is scarce. This lack of data is mostly attributed to contractual restrictions regarding the release of information to third parties. Furthermore, most of these activities are temporary in nature, which makes it difficult to track and record their energy use patterns. The actual diesel consumption in single-activity electricity generation is, therefore, likely to be much higher than estimated in this report.

Data from Yemen's telecom companies show an estimated annual diesel consumption of 18,000 tonnes in this sector. Telecom companies Egypt, Sudan and Yemen have explored introducing PV into their base stations, while some have already begun to conduct feasibility studies or implement pilot projects.

2.2.4 Water pumping in agriculture

The economic significance of the agricultural sector varies from one country to another, ranging from 14.8% of GDP in Egypt to 28% in Sudan (World Bank, 2014). All four countries, however, use diesel pumps extensively. Agriculture tends to be a rural activity that takes place in areas that are not covered by national grids in developing countries. It is the sector with the highest diesel consumption in most of the target countries, estimated at approximately 5.5 million tonnes per year. With low percentages of grid connectivity, Djibouti, Sudan and Yemen are especially dependent on diesel for water pumping.

In Egypt, despite the high electrification rate, agricultural farmland is increasingly located in off-grid areas, particularly mega-farms in the Western Desert which cultivate crops intended for export. Some of these farms are tens of thousands of acres in size and have more than 7 MW of diesel-based pumping systems. Egypt is thus the country with the highest potential for solar retrofitting in the agricultural sector. Agriculture on new reclaimed lands usually uses groundwater for irrigation. Larger pumps are needed which run between 12 to 24 hours a day, depending on the season. In some cases, additional desalination units are used to purify the high salt content of the ground water. These desalination units also run on diesel and can be retrofitted to run on solar PV.

The following table presents the estimated diesel consumption in the four diesel-intensive applications in the four countries:

Table 1 - Diesel consumption figures for the four countries (000s tonnes)

Category (000s tonnes)	Djibouti	Egypt	Sudan	Yemen	Total
Utility mini-grids	5	78	40	223	346
Private mini-grids	20	60	-	78	158
Single-activity applications	-	-	-	16	18
Water pumping in agriculture	0.7	3,775	52	1,648	5,475.7
Total	25.7	3,915	92	1,965	**5,997.7**

2.3 Available solar solutions

The four target diesel-intensive applications can be retrofitted with various commerically-available solar systems depending on the energy load profile, grid connection and diesel dependency.

In a **stand-alone solar solution**, solar energy completely replaces the diesel gensets. It is the simplest form of a solar system as it only generates solar energy to power the connected devices when sufficient sun irradiation is available. The cost of a standalone system is relatively low compared to more complex systems. Maintenance and operation costs are are also low compared to conventional diesel gensets. This solution is appropriate for applications in which energy is only needed during the day and budget is a constraint, such as in simple agricultural pumping for small farms.

The main drawback of a standalone solar system is its unavailability at night and on cloudy days. To overcome this limitation, a battery bank to store electricity is needed, which increases the initial cost of the system as well as operations and maintenance costs. A standalone solar system with a battery bank is usually appropriate for telecom base stations.

Hybrid solutions combine solar technologies with other power sources, such as diesel gensets or wind turbines. Hybrid systems can be more cost-effective because they do not require large battery banks. Maintenance and replacement costs are also relatively low in comparison to diesel-only systems. The **fuel saver** option is a hybrid application in which solar panels and diesel gensets operate simultaneously throughout the day in order to secure a stable electricity supply independently of grid connection. The simultaneous operation of solar and diesel generators requires a control system to ensure optimal utilization of both technologies to maximize the solar fraction[1] during sun hours. To improve the efficiency of the system, diesel gensets should be configured to ramp up and down production based on the availability of power from the solar panels. Fuel savings of up to 30% can be achieved (Aschoff Solar, Fraunhofer ISE, & Steinke , 2014). Fuel-saver hybrid solutions are particularly well-suited for mini-grids.

Fuel savings may increase beyond 30% by adding **smart grid** features to enable closer management of the mini-grid. The system is equiped with adequate sensors to enable two-way communication between various components of the system and to monitor solar irradiation. Active components in the grid are connected for exchanging basic information about their state of operation and transfer of power. A centralized management system continuously adjusts generation and loading based on the availability of the solar resource. Multiple hotels or pumps on a farm can be connected to one centralized grid. (Aschoff Solar, Fraunhofer ISE, & Steinke, 2014).

For agricultural pumping, special inverters can be used. Such inverters are based on **frequency inverters** or so-called **variable speed drives** (VSD). They were especially developed for applications with pumps or other three-phase motors with similar characteristics. The hybrid systems using VSD are simple to set up even on existing farms, as only a solar system is added to the well. During sun hours the solar system is running the pump according to the same principles as for a stand-alone system running only on solar energy. If the solar output is lower than the minimum power required for the pump, the system switches to diesel genset operation. This switch is done by a **switch control**. Fuel savings are dependent on the total required irrigation time and the designed operating time of the solar system.

Water reservoirs can also be deployed in the solar irrigation system as water pumped during sun hours can be stored in the water reservoirs or high tanks. They not only serve as water storage, but can also be used to purify the pumped groundwater to increase the efficiency of the irrigation system on the farm. Building water reservoirs on farmlands eliminates the need for costly battery banks and offers the possibility to irrigate at night, minimizing the diesel consumption. The water is then only distributed across the fields using small booster pumps (Aschoff Solar, Fraunhofer ISE, & Steinke , 2014).

2.4 Solar retrofit potential

The following table presents the estimated potential PV capacity in the four diesel-intensive applications in Djibouti, Egypt, Sudan and Yemen:

Table 2 - Potential PV peak capacity for the four countries (MW_p)

Category (MW_p)	Djibouti	Egypt	Sudan	Yemen	Total
Utility mini-grids	0.7	82	53	280	415.7
Private mini-grids	7	77	-	76	160
Single-activity applications	-	-	-	5	5
Water pumping in agriculture	0.5	1,938	101	894	2,933.5
Total	8.2	2,097	154	1,255	**3,514.2**

3 The way forward

As discussed in the previous chapter, there is significant market potential for solar PV retrofitting of diesel-based systems in off-grid areas in Djibouti, Egypt, Sudan and Yemen. Such projects would bring about much needed economic, environmental and socio-economic benefits to the countries' remote areas. However, research and stakeholder consultations have revealed many "soft" barriers in all countries preventing wide-scale solar PV-hybridization of diesel-based power systems.

Addressing these barriers requires an engaged and wide network of local, national and international stakeholders. These stakeholders provide continued understanding from an on-the-ground perspective, contribute market development insights, monitor and report change and play a vital role in the development and implementation of support programs. Indeed, a comprehensive strategy relying on the close involvement of stakeholders is key to tapping into this market potential for solar energy and catalyzing transformational economic, social and environmental benefits to rural communities.

3.1 Situational analysis

The study has identified three main impediments to wide-scale deployment of solar PV hybrid solutions: **low awareness**, **insufficient implementation capacity** and **perception of high risk**. Taken together, these hurdles complicate access to finance and lead to an unfavorable market environment for solar PV retrofits in off-grid remote areas. Consultations with various market actors and stakeholders including end users, technical solution providers, government and public agencies, development organizations and financial institutions in all four countries have confirmed the findings.

1. Low awareness:

Although the global solar PV market has developed rapidly in recent years due to technological advancement and falling costs, research and interviews conducted during this study show that the potential benefits of solar PV are not fully understood in the Arab region. There is a general lack of awareness on solar PV hybrid solutions among energy users, energy service providers and policy makers. Common knowledge gaps include:

- Low awareness and understanding of the existing technical solutions to retrofit existing diesel-based systems with solar PV technologies. This awareness gap is particularly prevalent among energy users in the industrial, tourism and agricultural sectors. Many end users in the industrial and tourism sectors cited during the interviews a common misperception about electricity from solar PV not being "strong" enough to power machinery and air-conditioning.

- Most energy service providers and technical solution providers that were interviewed for this study did not view solar retrofits as a potential market segment with profitable investment opportunities for solar PV. These service providers continue to steer their off-grid clients toward diesel gensets. They were completely unaware of the fact that companies in Sub-Saharan Africa and parts of Asia have been making profits from marketing solar PV solutions for off-grid systems.

- Low awareness and understanding, particularly among policy makers, of the potential economic, socio-economic and environmental benefits of solar PV retrofitting of off-grid diesel power systems.

2. Insufficient implementation capacity:

Generally speaking, market actors in the four countries suffer from insufficient implementation capacity at most stages the value chain, including (1) identification and design of profitable projects, (2) development of financing packages that reduce risk to investors, (3) implementation of public support schemes for the promotion of decentralized solar energy applications and (4) delivery of after-sales operations and maintenance support. A particularly important gap lies in the absence of local business models that are tailored to the specific market conditions in each of the four countries, which are key to market-oriented solar energy solutions. Other common barriers that emerged in the study include:

- Energy users that were interviewed in this study do not have an energy manager on site. The site engineers in these facilities do not have firsthand experience with solar energy. They also do not have sufficient training to solicit technical and financial offers from service providers for solar retrofits, much less evaluate these offers.

- Most solar solution providers have not had experience with hybrid solar systems. Their experience has been limited to simple solar home systems or solar pumps. This lack of experience has hindered their ability to identify, design and implement solar PV hybridization projects.

- Most solution providers also suffer from insufficient "business development" capacity to understand their markets, attract clients and develop appropriate business models for solar PV hybridization solutions in off-grid remote areas. For the most part, solar solution providers approach their business as a retail business, not as an energy service business.

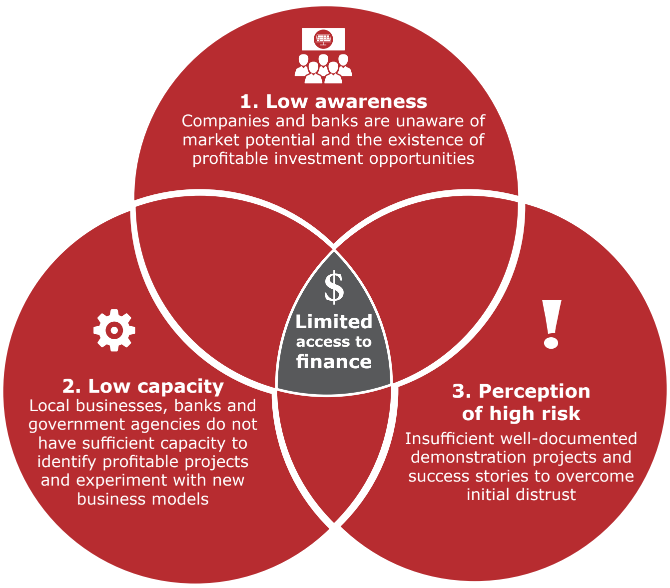
- Bankers interviewed in this study do not have the necessary financial models and tools to evaluate loan applications for solar projects. Even when these tools have been made available, banks still do not have sufficient in-house analytical and technical capacity to understand and use these tools.

- Although some policy makers and civil servants have expressed interest in promoting solar PV retrofits in remote areas, they lack the technical and financial knowledge to design and implement cost-effective support programs to create and upscale this market.

3. Perception of high risk:

Another barrier is the perception of high risk associated with solar energy technologies. Most of the bankers interviewed during this study expressed serious doubts about the accuracy of the expected energy and financial savings from retrofitting diesel-based systems with solar PV. Even some energy solution providers seemed doubtful that solar PV systems are as reliable as diesel gensets. Energy users in off-grid areas are particularly alarmed by stories of failing solar equipment; although when asked to point to a specific example, they admit to not having firsthand knowledge of such failures. These misperceptions can be attributed to the absence of well-publicized success stories that serve to dispel these myths and demonstrate the reliability and benefits of solar PV systems. The perception of high risk has been a limiting factor to the development of solar energy markets in these countries because they prevent actors across the value chain from investing in them.

Figure 2 – Three problem areas inhibiting market development of off-grid solar energy applications in focus countries



There are other region-specific issues that affect the market uptake of these solar PV hybrid solutions in off-grid remote areas. They include issues such as:

- Regional conflict and political turmoil in certain countries at time of writing
- Slow market liberalization and rigid market structures
- Unsupportive and unharmonized economic policies regarding solar energy and the importing or manufacturing of solar energy equipment

3.2 Stakeholder involvement

Enabling the uptake of decentralized solar energy solutions in the Arab region cannot take place without involving local stakeholders. Engaging various stakeholders in each country is instrumental to developing a broader situational understanding, gauging market potential and transforming the market through concrete projects. A real-time assessment of the stakeholders' perspectives, concerns and needs helps to build a more comprehensive picture of the situation on the ground. This study conducted a preliminary stakeholder mapping and consultation exercise with diverse stakeholders in Djibouti, Egypt, Sudan and Yemen to complement the quantitative research.

The report focused on mapping and targeting five different stakeholder categories: energy end users, technical solution providers, government and public agencies, development organizations and financial institutions and investors. Throughout the study, representative stakeholders were involved in the data collection and consultation process, although certain private sector actors expressed reservations on providing detailed information and insights due to contractual restrictions and confidentiality agreements.

Table 3 - Stakeholder categories consulted in the report

Stakeholder category	Examples
1. End users	*Hospitals, army bases, hotel owners, farms, etc.*
2. Solution providers	*Local diesel providers, local solar energy providers, etc.*
3. Government and public agencies	*Ministry of energy, ministry of development, sustainable energy agencies, etc.*
4. Development organizations	*UN organizations, international NGOs, foundations, etc.*
5. Financial institutions and investors	*National banks, commercial banks, national funds, etc.*

Typically, stakeholders vary from country to country, but can be assessed in terms of their awareness of decentralized solar energy technologies, their influence and willingness to embark on these projects, their capacity to do so and their access to capital. Each stakeholder category differs in knowledge, experience with solar energy solutions, needs and capacity. Stakeholders assess the market situation differently, and their specific areas of expertise can address different market development hurdles. Taken together, a fuller picture of the market potential for off-grid solar energy emerges, including the barriers that currently impede its development and the incentives needed to move forward.

At later stages, the preliminary stakeholder mapping conducted in this study can lead to a proactive engagement strategy to drive the uptake of off-grid solar energy solutions and practices. Stakeholders can be targeted with awareness-raising and capacity development activities based on their needs. Different stakeholders can be brought together to implement pilot projects and form business and technical networks which will amplify the impact of their individual actions.

The most relevant stakeholders for each country vary depending on the targeted sector. Overall, governmental and public agencies are key stakeholders across all four countries given the high degree of government pariticipation in managing economic activities in general and particularly in the energy sector. Typically, ministries of electricity and energy need to be involved in permits and power agreements, whereas ministries of economics, trade and investment determine large parts of the procedures for customs, land permits, fuel subsidies, taxation and fiscal incentives, all of which determine the feasibility and profitability of solar retrofits. In Sudan, for example, off-grid solar energy applications are difficult to implement and install because the customs duties on solar equipment are prohibitively high. Given their influence and access to public funds, government agencies can facilitate the introduction of market-specific business models and financial incentives to promote solar retrofitting projects in off-grid areas.

Solar energy solution providers exist in all four countries and are eager to develop this new market segement. However, they openly acknowledged the need for technical and business development training and easier access to funding. Many local banks and financial institutions have expressed their willingness to work with solar solution providers to finance these projects. However, they also may benefit from awareness-raising and technical assistance to become more comfortable with the technologies and financial models involved. Development agencies with local presences, such as UNDP, are well-positioned to bring these stakeholders together in a systematic, integrated way, to empower individual actors and create market momentum.

3.3 Proposed actions

This study has identified three broad categories of activities that can accelerate the creation and scaling up of solar retrofit markets in Djibouti, Egypt, Sudan and Yemen as well as other Arab countries. The proposed actions aim to address the three main impediments to the market outlined earlier in the chapter: low awareness, insufficient implementation capacity, and the perception of high risk. In order for these activities to yield the desired results, they should be carried out in an integrated manner and coordinated on a regional level in order to capitalize on regional synergies and economies of scale in the implementation of solar PV retrofitting in the four countries and beyond.

3.3.1 Market assessment and awareness building

While this report provides a high-level assessment of the market potential for solar retrofits, investors, banks and policy makers need more detailed market information in order to identify bankable projects and design informed policies. Target applications identified for future market assessments include agriculture in Djibouti, Egypt, Sudan and Yemen; mines and hydrocarbon extraction sites in Egypt and Sudan; mini-grids in Djibouti, Egypt, Sudan and Yemen; and industrial facilities in Egypt and Yemen. The market assessments should include field surveys and site visits to specific companies in these sectors. Field surveys will not only improve the quality of the data, but will also help identify potential solar retrofit projects and eventually generate a pipeline of bankable projects for solar solution providers and financial institutions.

Future market assessments and field surveys should also examine existing business models for power generation and distribution in these sectors. This exercise will help identify the business models that are more likely to succeed in the target countries and sectors.

The knowledge generated from these assessments should be disseminated to key stakeholders in each country in order to build their awareness and increase the possibility of their involvement in further activities to develop the solar retrofit market. A region-wide network of relevant stakeholders may be an effective channel to engage and facilitate knowledge exchange among them. This network will help disseminate lessons learned and success stories within the region and will serve as a platform for policy dialogue and the formation of public-private partnerships in support of this market.

3.3.2 Capacity building and technical tools

A successful intervention to create and upscale the solar retrofit market should build the technical capacity of solar solution providers to design, implement and maintain such systems. Without such capacity, it will be difficult to imagine a profitable and sustainable market for solar retrofits in these countries. However, boosting the technical capacity of solution providers will not be enough to generate momentum in this market.There should be a special focus on building the capacity of solution providers and financial institutions in non-technical areas, such as business development and marketing, business model design and financial product design.

Capacity building activities should be coupled with the development of a suite of appropriate technical and financial tools to be used as reference material by banks, end users and solution providers. These tools should be made available to market actors in order to reduce transaction costs and avoid unnecessary delays in project design, financing and implementation. The availability of these tools will serve to standardize and streamline credit approval processes which would make financing more accessible.

3.3.3 Pilot projects

The absence of existing, operational solar hybrid systems is the main source of the perception of high risk discussed earlier in this chapter. Pilot projects serve as a living proof of the reliability of these technologies and their positive impact on business profitability. In fact, interviews conducted for this study have shown that the perception of risk is the lowest in Egypt, which is the only country with existing examples of solar-diesel hybrid systems in off-grid areas.

Similar pilot projects should continue to be implemented in Egypt and the other three countries. To reduce the risk of failure, each pilot project can be supported by a voluntary public-private partnership (PPP) consisting of relevant actors, including energy end users, technology providers, Islamic and commercial banks, development organizations and government entities. Pilot projects should be monitored and evaluated to identify success stories to be widely disseminated.

4 Country Specific Analysis: Djibouti

Table 4 - Key socioeconomic and energy facts for Djibouti

Population	HDI ranking	GDP (USD)	Electrification rate	Diesel price (USD per Liter)
872,900 (World Bank, 2013)	**164 out of 187** (United Nations Development Programme, 2013)	**1.456 billion** (World Bank, 2013)	**50%** (Africa-EU Energy Partnership, 2013)	**1.18** (World Bank, 2014)

Djibouti's economy depends primarily on its strategic location along the Red Sea. It has a strong market potential for decentralized solar energy applications, in particular for utility-mini grids and for agricultural water pumping. Until 2011, Djibouti was highly reliant on diesel power plants to supply its main grid, but diesel is gradually being phased out and replaced by hydroelectricity imported from Ethiopia. Djibouti's electricity infrastructure has not kept pace with the country's economic development, leading to frequent load shedding and black-outs in urban areas and persistent lack of access to electricity in peri-urban and rural areas (IRENA, 2015).

4.1 Diesel consumption trends in remote areas

4.1.1 Utility mini-grids

Division North is an isolated grid in north-central Djibouti, which serves private and public sector consumers in the cities of Tadjoura and Obock. The grid is not connected to the Ethiopian interconnection and depends solely on diesel power plants to meet the needs of its consumers. Due to the relative remoteness of Tadjoura and Obock, there are no plans to connect the Division North mini-grid to the main national grid of Djibouti nor to include it in the interconnection with Ethiopia (Parsons Brinckerhoff, 2009) (RCREEE, 2015). The Division North isolated grid seems to be an attractive investment opportunity for solar PV retrofitting.

The Tadjoura power plant has 6 x 600 kVA diesel gensets, with a total generating capacity of 2.2 MW. Obock's power plant includes 3 x 400 kVA and 2 x 600 kVA diesel gensets, with a total generating capacity of 1.2 MW. Four of Tadjoura's gensets and three of Obock's gensets were commissioned in 2005 and are approaching the end of their useful life (EUEI-PDF, 2013). A golden opportunity exists to replace the aging gensets with solar PV arrays, especially when taking into account that demand will exceed the generating capacity in these two plants in the short-term.

At the average demand load factors, the Tadjoura plant is estimated to consume 2,970 tonnes of diesel per year, while Obock consumes 1,980 tonnes of diesel. The two plants release CO_2 emissions of approximately 15,000 tonnes per year (Parsons Brinckerhoff, 2009) (Caterpillar, 2013).

4.1.2 Private mini-grids

As a result of the electricity shortage in Djibouti, large consumers of electricity, such as national ports and commercial facilities, have resorted to commissioning private diesel power plants to meet their electricity needs. For example, the Grain and Fertilizer Terminal in the Port of Djibouti, inaugurated in 2006, has its own 1,700 kVA diesel power plant (Visscher, 2011). The Doraleh Container Terminal, which started operating in 2008, reportedly has its own diesel power plant, although the capacity of the plant is not publicly available. With the Port of Djibouti expanding, there will be growing potential for solar hybridization of diesel power plants.

Due to its strategic location in the Horn of Africa, Djibouti hosts multiple foreign military bases. At least one of those bases, Camp Lemonnier, is 100% dependent on diesel gensets with an effective aggregate capacity of over 18 MW. The gensets consume over 20,000 tonnes of diesel and release over 60,000 tonnes of CO_2 per year. With an average estimated cost of generation of at least USD 0.30 per kWh, solar PV is a competitive solution with relatively short payback periods and high returns on investment (Anderson, 2013). The land lease for Camp Lemonnier was renewed in 2015 for 10 years, which reduces the off-taker risk for any private investor who may want to undertake this investment (Oladipo, 2015).

4.1.3 Water pumping for irrigation

According to the Ministry of Agriculture's 2009-2018 plan, the area equipped for irrigation in Djibouti is 1,250 hectares of the total cultivated area of 2,000 hectares. Since this figure was published in 2009, the area of irrigated land most likely has increased over the last 6 years. Djibouti's agricultural water withdrawal is 3 million m^3 per year, at least two thirds of which comes from groundwater sources (Aquastat, 2015) (Ministre de l'Agriculture, de l'Eau, de la Pêche, de l'Elevage et des Ressources Halieutiques, 2009).

Information regarding the number of installed pumps or general data on diesel consumption in agriculture is, however, very scarce. Based on the methodology outlined in Appendix B, the annual consumption of diesel for crop irrigation is approximately 740 tonnes with resulting carbon emissions of over 2,000 tonnes per year.

4.2 Market potential for off-grid solar energy

Table 5 – Off-grid solar energy market potential in Djibouti

Target applications	Diesel consumption (000s tonnes/year)	Potential PV capacity (MW_p)
Utility mini-grids	4.95	0.7[2]
Private mini-grids	20	7
Water pumping in agriculture	0.74	0.5[3]

4.3 Barriers and support programs

Cost is often cited as the main barrier to solar PV projects in Djibouti. Many stakeholders complained about high import taxes on solar equipment: 30% for solar panels and 33% for other solar energy equipment such as batteries and inverters. Solar PV companies and solution providers reportedly charge significant installation as well as maintenance costs due to the scarcity of qualified local technicians and engineers.

Most stakeholders agree that the lack of appropriate and affordable financing options exacerbates the cost barrier. Although bank loans exist in theory, access to finance remains difficult due to low awareness and perception of high risk. Stakeholder consultations have revealed a serious knowledge gap. Investors and policy makers struggle to make informed investment decisions and policies due to the lack of concrete, reliable statistics about private sector activities and corresponding energy consumption in off-grid areas. Data about water pumping and private mini-grids serving industrial and commercial facilities is particularly scarce and difficult to access.

Such uncertainty about the market size and its potential makes off-grid solar electrification appear too risky to financial institutions and private sector investors. Stakeholders have highlighted the need for more feasibility studies, market potential reports and awareness-raising regarding solar energy technology.

Djibouti's government seems committed to overcome these barriers. Replacing diesel with solar energy has been on its radar since early 2000s. The government has set an ambitious target to generate 100% of the country's electricity from renewable sources by 2020 (IRENA, 2014). To achieve this target, the government of Djibouti has adopted multiple support policies and programs for renewable energy, including the recent adoption of Law No. 88/AN/15, which encourages private production of electricity from renewable energy to sell to the national utility or for self-consumption.

Following the increase in fuel prices in 2000 due to subsidy removal, Djibouti's government launched a large number of projects for substituting existing diesel pumps with solar PV in rural areas. In 2006, approximately 55 wells were equipped with solar PV systems of 5 kW each, ensuring permanent water supply for rural populations (Ministère de l'Habitat, de l'Urbanisme, de l'Aménagement du Territoire et de l'Environnement, 2012). Based on this demonstration of political will and the existing government policies, off-grid areas have high potential for solar PV retrofitting projects for water pumping.

In the National Strategy for the Promotion of Solar Energy, developed in 2008 with support from UNDP, the government of Djibouti committed to equip over 70 wells with solar pumps and to electrify over 5,000 households, 100 schools and all rural health clinics with solar energy. Djibouti's government has also committed to provide grants and financial incentives for renewable energy applications in households and public lighting through Act 167/AN/12 (League of Arab States, 2013). However, there do not seem to be support programs specifically for private investments in solar retrofitting of small-to medium-size solar power plants or water pumping in the agricultural sector.

4.4 Key stakeholders

4.4.1 End users

In preparing this chapter on Djibouti, the study team interviewed a sample of energy end users, including hotels, medical centers and a telecommunications company. The consultations with energy consumers revealed a general interest in incoroprating solar energy technologies into their systems. However, these energy users for the most part did not have first-hand experience with solar PV technologies, nor did they have the capacity to procure such technologies for their facilities. The only exception is Djibouti Telecom, which currently has solar energy applications installed for some operating towers and plans to increase its investments in solar energy solutions.

4.4.2 Solution providers

Djibouti has a number of local solution providers with past experience in off-grid solar energy applications, which is remarkable for a country of its size and level of economic development. The presence of these solution providers will facilitate the creation and scaling up of the solar energy market in Djibouti. However, while these solution providers have technical experience in installing and maintaining solar PV systems, their experience with business development and business model innovation is limited. According to one solution provider, his only experience has been with projects commissioned by development organizations or the government, because there was no demand from private customers. In order for this market to grow, technical assistance in business development and marketing is needed.

Djibouti does not have a trade association or network for solar energy solution providers. However, some solution providers are taking initiative to make their products more competitive with diesel gensets. The are currently working together with the Djibouti Chamber of Commerce to lobby for reduced import taxes on solar energy equipment (RCREEE, 2015).

4.4.3 Government and public agencies

In Djibouti, the most relevant public sector stakeholder is the Ministry of Energy and Natural Resources (Ministère de l'Energie et des Ressources Naturelles - MERN), which is responsible for developing and implementing energy policies. A stakeholder consultation with MERN confirmed the Ministry's awareness of the need of off-grid solar energy solutions in rural communities. The Public Utility of Djibouti (Electricité de Djibouti – EdD) is the most important stakeholder for interventions relating to the country's electricity infrastructure, including utility mini-grids. The National Energy Commission, responsible for implementing and monitoring the National Energy Master Plan, is another key stakeholder that needs to be involved.

The Ministry of Agriculture, Livestock and Fisheries (Ministère de l'Agriculture, de l'Eau, de la Pêche, de l'Elevage et des Ressources Halieutiques) is responsible for developing and implementing policies in the fields of agriculture and irrigation and has previous experience with solar water pumping programs.

Another key public sector stakeholder is the Djibouti Social Development Agency (Agence Djiboutienne du Développement Social – ADDS) that focuses on the development of various sectors including energy and water. ADDS has experience with solar energy pilot projects in Djibouti. The development agency is active in rural electrification and is responsible for implementing the national development initiative for poverty reduction in areas not covered by the EdD (IRENA, 2015). The energy component of ADDS is managed by the Directorate of Rural Electrification (IRENA, 2015).

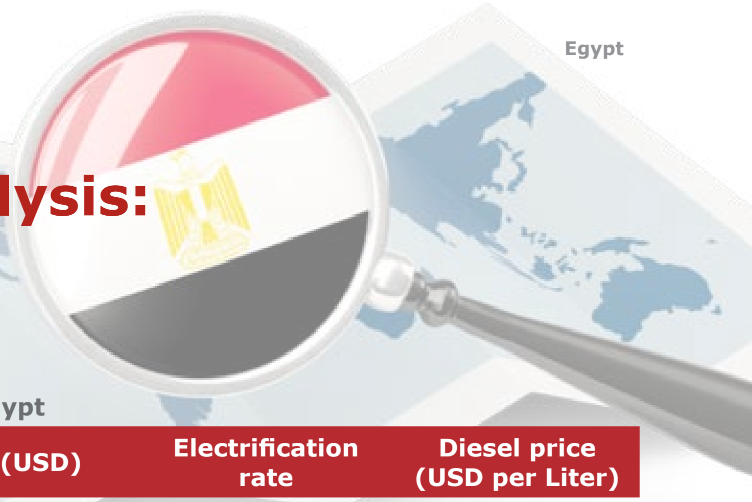
The Ministry of Economy and Finance (Ministère de l'Econome et de Finance) oversees industrial planning and sets the electricity tariffs by decree for the use of national utility Electricite du Djibouti (IRENA, 2015). The Directorate of External Finance is responsible for implementing and monitoring new projects (IRENA, 2015). The National Investment Promotion Agency (NIPA) is an independent private investments promotion agency that has a renewable energy focus.

4.4.4 Development organizations

Djibouti hosts multiple international development organizations that are typically present in Eastern African countries. These organizations also demonstrate a focus on decentralized renewable energy and solar pumping programs led by the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP).

4.4.5 Financial institutions and investors

Djibouti's banking sector is growing rapidly. There were 11 banking institutions in 2014, as opposed to two in 2006. However, the banking sector has not been active in financing renewable energy projects, and, therefore, banks are unlikely to have in-house capacity to assess and finance such projects. Consultations with banks point towards the absence of programs for renewable projects due to perceived low demand and lack of government support to co-finance.



5 Country specific analysis: Egypt

Table 6 – Key socioeconomic and energy facts for Egypt

Population	HDI ranking	GDP (USD)	Electrification rate	Diesel price (USD per Liter)
90,000,000 (Central Agency for Public Mobilization and Statistics, Nov 2015)	**110 out of 187** (United Nations Development Programme, 2013)	**272 billion** (World Bank, 2013)	**99%** (Arab Union of Electricity, 2013)	**0.23** (World Bank, 2014)

The great majority of Egypt's population is concentrated along the Nile Valley and Nile Delta with 42% living in urban areas. Egypt's population of more than 90 million lives on only 7.7% of the country's land area according to the Central Agency for Public Mobilization and Statistics (CAPMAS). The highly populated Nile Valley and Nile Delta regions are almost entirely connected to the national power grid, resulting in 99% electrification rate of households and businesses. However, many economic activities, particularly in agriculture, tourism, mining and other extractive industries, take place in desert areas east and west of the Nile and rely on diesel gensets.

Reliance on diesel power systems has been on the rise in Egypt. According to CAPMAS, Egypt imported over USD 300 million worth of diesel generators with plate capacities of 75 kVA or higher between 2010 and 2014. As reported by farms in and around Wadi Natroun and the Western Desert, prices of diesel gensets and parts have spiked roughly 40% over the past 3 years, due to the frequent use of these gensets as backup systems in various sectors affected by blackouts and the rapid agricultural expansion into new reclaimed lands.

Within Egypt, the main sectors of interest for solar energy are tourism and agriculture, as they belong to the largest sectors in terms of employment and GDP. In both sectors, many activities in remote areas are either partially or entirely dependent on diesel gensets. However, there is also a growing market for mini-grid solar systems for residential use, as approximately one million Egyptians live in population centers outside the national grid. Real estate developments outside major cities increasingly consider solar systems to meet the rising energy demand.

Despite the high electrification rate of 99%, Egypt has been suffering from an energy shortage since 2008. In 2014, Egypt's electricity demand amounted to 27,700 MW, 20% above the country's power production capacity (Kingsley, 2014). Rapid population growth, summer heat waves and outdated, inefficient power plants are reasons for frequent power outages in recent years, although the situation began to improve in 2015 with the addition of new power plants. Electricity demand, met primarily from natural gas (47%) and oil (43%), will likely reach 57,000 MW in 2027, an increase of around 30,000 MW in just 12 years.

The cost of energy in Egypt is highly subsidized by the government. The retail price of diesel fuel is USD 0.23, while the cost of importing it is reportedly higher, although exact figures are not readily available. Government subsidy spending amounted to USD 18.2 billion in oil product subsidies and USD 1.8 billion on electricity subsidies in the fiscal year of 2013/2014. Energy supply shortages and the perceived diminishing hydrocarbon reserves of Egypt have led to the introduction of the five-year plan to remove fossil fuel subsidies entirely. The government aims to achieve international market prices on fossil fuels by 2019. The first adjustment of diesel price in the second quarter of 2014 amounted to a 63% increase. Agribusinesses are reportedly expecting to pay around USD 0.70 to USD 1.00 per liter in 2019 including transportation costs to the site.

Solar energy is increasingly seen as a cost-effective alternative energy source, particularly to meet the growing energy demand in off-grid areas across the sectors of agriculture, tourism and extractive industries.

5.1 Diesel consumption trends in remote areas

5.1.1 Utility mini-grids

Utility mini-grids in Egypt show significant potential for solar retrofitting initiatives. According to the 2013 Annual Report of Egypt's national utility the Egyptian Electricity Holding Company (EEHC), the country has 29 isolated diesel power plants in remote areas. These plants feed electricity into local mini-grids, which are managed by four distribution companies (table 7). EEHC reported that they consumed 78,000 tonnes of diesel in 2013, which resulted in over 200,000 tonnes of annual CO_2 emissions.

Table 7 - Isolated diesel power plants in Egypt

Company	Number of plants	Installed capacity (MW)	Gross energy generation (GWh/year)
Canal DC	18	145	184.7
El-Behera DC	4	12.3	30.7
Middle Egypt DC	6	41.3	24.3
Upper Egypt DC	1	2.9	-
Total	**29**	**201.5**	**239.7**

Solar hybrid home systems in remote villages

An Egyptian solar company, Complete Energy Solutions, has installed 2.5 MW solar hybrid mini-grids systems for 3,441 homes in Sohag (Upper Egypt), Marsa Matrouh (North Coast) and North and South Sinai. The solar systems are mini-grids solutions backed by diesel gensets to serve 24-hour electricity to the remote villages. These 3,441 homes had been completely reliant on diesel gensets. During times of diesel shortage, they had no access to electricity.

The project has been funded by the United Arab Emirates under the grant to Egypt for solar energy retrofitting.

5.1.2 Private mini-grids

Private mini-grids that are retrofitted with PV solar energy are the most economical solution for many industries without a connection to the national grid. Especially on new desert farms and hotel resorts, centralized mini-grids systems supply energy to a network of outlets and often result in the most optimal solution compared to decentralized systems.

Tourism Sector

While the tourism sector accounts for 15% of Egypt's GDP, not all tourist destinations are connected to the national electricity grid. Many hotels and resorts along the Red Sea and Mediterranean coasts are not connected to the national grid and are entirely dependent on diesel for all operations including water desalination. These hotels carry significant potential for solar retrofitting.

An example of this untapped potential are the hotels in and around Marsa Alam, a resort area by the Red Sea, which is 100% dependent on diesel for electricity generation. There are more than 56 hotels with 12,500 hotel rooms in Marsa Alam. With an average annual diesel consumption of 5,600 liters per room, Marsa Alam's hotels consume approximately 60,000 tonnes of diesel per year and release around 200,000 tonnes of CO_2 emissions into the atmosphere.

Many hotels have not been able to secure sufficient diesel for all their operations in the past four years and had to buy fuel at a premium through the informal market. The sector will be further pressured as a result of the expected increase in diesel price per liter from 1.8 EGP (= USD 0.23) to 5 EGP by 2019 when the subsidy is fully removed. Many hotel owners are beginning to see solar energy as a way to lower operating costs and avoid service disruptions.

Pilot projects in the tourism sector

Lahamy Bay Beach Resort and Gardens in Marsa Alam

Lahamy Bay Beach Resort and Gardens is a beach resort and diving center on the coast of the Red Sea. The 184-room resort is situated 120km south of Marsa Alam.

The resort entirely relies on diesel fuel using multiple gensets amounting to 2 MW, and its owners aspire to install a 650 kWp solar PV system onto the diesel mini-grid.

As a first step, the hotel owners installed a 13 kWp solar system in 2014. The pilot project will help them gain experience in operating a solar system.

Other Industries

In addition to tourism, Egypt's extractive industries, including mines and petroleum sites, are ideal candidates for solar retrofitting, although their potential has been difficult tso quantify due to scarcity of data. An example of this potential is the Sukari gold mine, west of Marsa Alam, with 40 MW of installed of diesel genset capacity. This mine has had difficulties securing diesel to maintain operations in the past few years, particularly in 2013 when it temporarily shut down its operations due to diesel shortages. Similarly, informal discussions with companies connected to Egypt's petroleum industry revealed that the installed capacity of diesel generators varies from one natural gas or oil site to another, ranging between 3 MW for the smaller sites all the way to 300 MW for larger ones.

5.1.3 Single-activity applications

The telecom industry in Egypt relies on diesel gensets to power network base stations in remote areas. In 2012, Mobinil, one of the main telecom companies in Egypt, operated over 150 off-grid stations which would benefit from solar retrofitting. Of these 150 stations, approximately 50 have sufficient loads to justify hybrid PV/diesel solutions. The remaining sites are small enough to convert completely to PV and battery storage without needing a backup diesel genset. The estimated potential savings in diesel consumption related to these retrofits is 1,870 tonnes of diesel per year (GSMA, 2012). This estimate is solely based on data from one company, Mobinil. With at least two more telecom companies operating in Egypt, the potential savings in diesel consumption from solar retrofits are likely to be much larger than stated in this analysis.

Some factories reportedly use diesel gensets to operate arc furnaces that consume higher loads of electricity than can be supplied by the national grid. These factories may have sigificant potential for solar energy retrofitting, but further investigation is required to determine the current levels of diesel consumption and the full potential for retrofitting.

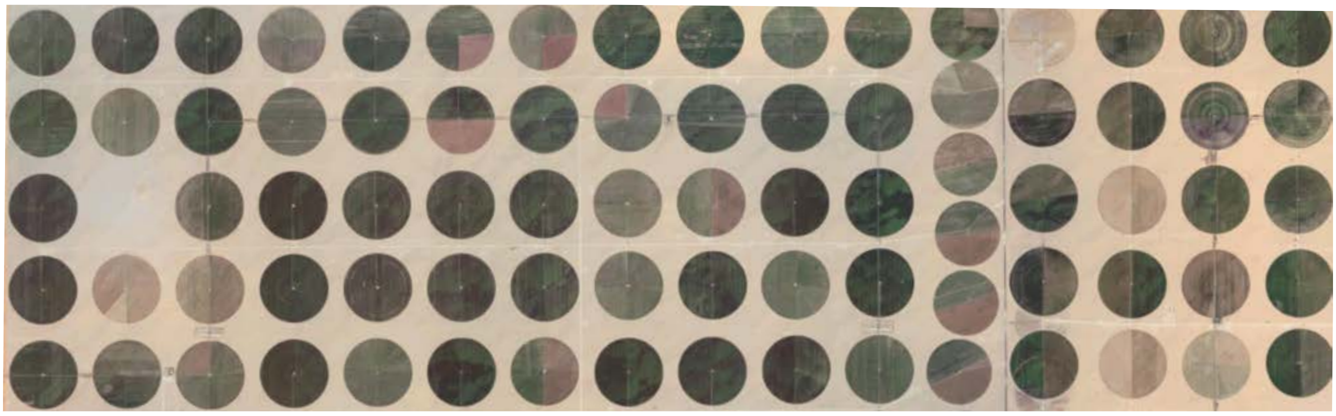
5.1.4 Water pumping for irrigation

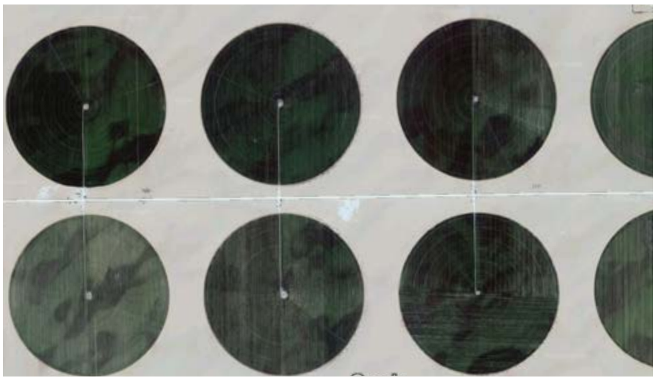
In 2014 Egypt's agricultural sector, one the country's top economic driving forces, accounted for 14.51% of its GDP (El-Nahrawy, 2011). Agriculture has the highest direct and indirect employment rate of 30% and 54%, respectively. In 2014, the Ministry of Agriculture reported that a total of 9.29 million acres were cultivated in the country of which 6.09 million acres were in the Nile Valley and Delta region, the "old lands," and 3.2 million acres in the reclaimed "new lands."

The Nile valley and Nile Delta regions are primarily cultivated by small holders (less than 5 acres) that make up around 90% of farmers in Egypt. The increasing re-zoning of agricultural land for residential use has limited the availability of fertile land along the Nile, which forced large-scale agricultural companies to expand into desert areas. Land reclamation for agricultural use is one of the top priorities of the Egyptian government. According to the Ministry of Agriculture and Land Reclamation, Egypt plans to increase its agricultural production level by reclaiming 1.5 million acres of desert land by 2017 and another 3 million acres by 2030 (El-Gindy, 2011).

The energy intensity of irrigation in the new reclaimed lands and the lack of grid connections to meet this need constitute the biggest challenge for this plan. Currently, farms in new lands use diesel-powered pumps to feed their irrigation systems. Increasingly, farms in the old lands are also using diesel pumps to supplement the electrical grid-connected pumps due to power shortages.

Based on examples of farms in the new lands, an average genset burns approximately 30 to 40 liters of diesel fuel an hour to power a single pump that will draw 100 m^3 from a depth of around 180 meters to irrigate 25 - 60 acres. The low efficiency of diesel generators, due to oversizing and overheating, results in high operating costs of the irrigation system. Furthermore, the poor infrastructure in and around the new lands makes the transportation of diesel a risky and costly activity. In the past few years, many farms have installed large diesel reservoirs to store diesel for times of shortage. Despite having already built and secured many diesel reservoirs, agriculture companies reportedly continue to face shortages, especially during spring and summer.





Off-grid potato farm in south-west Egypt

So far, Egypt's government has built 600 wells across the south of the Qattara, Toushka, Farafra Oasis and in the Western Desert to supply new farms with water. Given the challenges relating to diesel, the government has announced plans to power new wells with solar energy (Al-Ahram Online, 2015). To secure sustainable water management and lower energy intensity, farms in the new lands are required to use drip irrigation and sprinkler systems. Drip irrigation systems are preferred when using solar energy, as their low evaporation rate of approximately 5% makes irrigation during the hot sun hours possible without losing water or burning the crops.

Based on various Egyptian agricultural companies, the main areas for new farmland reclamation are:

- *Wadi Natroun*
- *Bahareya Oasis*
- *North and South Sinai*
- *Siwa*
- *Western Desert*
- *South Valley*
- *West Menya*

The government's solar pumping plans do not currently cover exisitng diesel-powered pumping systems in the new and old lands. An estimated 258,000 diesel-operated pumps are currently in operation out of the 880,000 pumps used for irrigation throughout the country as reported in the Bulletin of Agricultural Machinery and Equipment published by the Ministry of Agriculture (Egyptian Ministry of Agriculture, 2013). The estimated number of diesel-powered pumps includes 111,000 pumps that serve as primary irrigation pumps in the new lands. The remaining 147,000 diesel-powered pumps are used for backup purposes in grid-connected old-land farms.

In total, diesel-powered pumps in Egypt consume an estimated 3.7 million tonnes of diesel per year, and release over 10 millions tonnes of carbon emissions.

Table 8 – Estimated diesel consumption figures for irrigation pumping in Egypt

Nameplate capacity (HP)	Estimated operational capacity (kW)	Yearly energy consumption[4] (kWh)	Diesel consumption per kWh (gm)	Number of pumps	Total diesel consumption (000s tonnes)
Portable:					
< 5	2.625	15,750	400	45,599	294
6 – 9	5.625	33,750	350	89,951	1,086
10 – 12	8.25	49,500	300	36,178	549
> 12	10.5	63,000	250	15,467	249
Fixed:					
< 15	7.5	45,000	250	27,549	317
16 – 25	14.25	85,500	235	24,716	508
26 – 45	26.25	157,500	220	8,597	304
> 45	37.5	225,000	200	10,182	468
Total				**258,239**	**3,775**

As shown in Table 8, the diesel gensets powering the pumps vary considerably in size. The majority of Egypt's water pumps are used for relatively shallow depths (surface water or near surface aquifers) and use portable machines (over 80%). Most of the machines are below 9 HP (74% of the portable machines) and are over 20 years old (68% of all machines). In the old lands, most pumps only lift water from small branch canals of the Nile (Mesqa or Marwa level). In the new lands, the main water source is ground water, and depending on the aquifer depth, the pump size can vary from 40 to 130 kW. Unlike in the old lands, desert farms use sprinklers, pivots and drip irrigation. These irrigation systems require constant pressure. For solar energy to be a feasible alternative, the constant pressure can be achieved via water tanks, solar/diesel hybrid systems or water pressure management via an open irrigation system on the farm. The trend within the sector is clearly towards using more large-scale fixed pumps than portable, small pumps, due to diminishing farmland in the Nile Delta and Nile Valley regions.

Pilot projects in the agricultural sector in Egypt

Solar water pumping and agricultural photovoltaic greenhouses in the Bahareya oasis of Egypt

In March 2015, SEKEM, an Egyptian Sustainable Development Initiative with an organic farm based on the outskirts of Cairo, has installed a 60 kW stand-alone solar system on their desert farm in the Bahareya Oasis. The 60 kW polycrystalline solar system is operating a 37 kW pump irrigating 60 acres of date palms. As the farm has an open irrigation system, the pressure can be regulated by opening and closing the water valves. Therefore, the higher the output of the system (higher irradiation), the larger the space that can be irrigated at a time.

Until today, the system delivers in average 800 m^3 a day with more than 1,000 m^3 a day during summer days. SEKEM decided not to use any diesel to back-up their solar system. Unreliable and costly diesel transportation to the farm is no longer part of the operating costs. The project has been installed by a German solar company, Aschoff Solar GmbH, together with a local partner, Egreen, and partly financed through the local leasing firm Tamweel.

After the successful installation of the first solar energy operated water pump, SEKEM has installed another solar system of 53 kWp at the end of 2015. It is the first Agri-Photovoltaic system in Egypt.

The Agri-PV solar system is constructed as a greenhouse offering shade for high-value crops, while producing solar energy. The 600 m^2 greenhouse uses a 18 kW submersible and a 12 kW surface pump for an expected average of 600 m^3 water output a day. The pumps are connected to an automated irrigation control system irrigating 18 acres of Jojoba plants and 30 acres of date palms. In order to store and filter the water from its high iron content, three water reservoirs have been installed.

The SEKEMs management is planning to rely 100% on solar energy for their entire irrigation system on the farm. The project has been installed by the Egyptian firms Egreen and Acropol and partly financed by the German Investment and Development Bank (DEG) and the Austrian Development Bank (OeEB).

KarmSolar, an Egyptian solar company specialized in solar pumping.

KarmSolar is an Egyptian solar company with a focus on solar water pumping for irrigated agriculture. Since their first contract for a solar-powered pump in 2012, the company has built and contracted 34 pumps in off-grid areas, which generate 1.7 MW in total.

KarmSolar is one of the largest private off-grid solar energy integrators in Egypt. The company has implemented Egypt's biggest solar off-grid hybrid pumping and irrigation system of 147 kW on a farm in the Bahareya Oasis.

5.2 Market potential for off-grid solar energy

Table 9 – Off-grid solar energy market potential in Egypt

Target Applications	Diesel consumption (ktoe/year)	Potential PV capacity (MW_p)
Utility mini-grids	78	82[5]
Private mini-grids	60	77.3[6]
Water pumping in agriculture	3,775	1,938[7]
Single-activity applications	1.87	0.09 (GSMA, 2012)

5.3 Barriers and support programs

In general, Egypt's current economic situation is the most significant barrier for the wide-scale adoption of decentralized solar energy solutions. Due to the devaluation of the Chinese Yuan, competition on a variety of goods including agricultural products has harmed many developing countries' export markets, including Egypt's. The overall demand for agricultural products has also decreased, due to the stagnating economy of Europe. The Egyptian tourism sector has been negatively impacted for five years due to the revolution and the perceived instability of the country. Further, the devaluation of the Egyptian pound has made the import of solar systems more expensive for local end users.

The Egyptian government has introduced several incentives to encourage investment in renewable energy. Two of the key incentives are (League of Arab States, 2013):

1. *The removal of customs duties for all renewable energy equipment and spare parts*
2. *Allocating land for renewable energy IPP investment*

A feed-in tariff program was introduced in Egypt in 2014. Producers of renewable electricity will receive a premium for the power that they sell to the utility for 25 years. The first round of the program, which was launched in late 2014, has received much attention from renewable project developers and investors, both domestic and international. However, decentralized utility isolated grids have been excluded from the program with no plans to include them in the near future.

The UAE has provided the Egyptian government with a grant to finance solar retrofits of utility mini-grids. The first project financed through this grant is the recently inaugurated large-scale PV-diesel hybrid system in Siwa. The 10 MW solar plant serves an isolated, utility mini-grid operated by El-Behera Distribution Company and produces electricity in parallel with the 4.5 MW diesel power plant already in place. Middle Egypt Distribution Company has plans to use the grant funds to install up to 6 MW of solar PV retrofits to hybridize Farafra, Abu Monqar and Qora Al Arbaeen diesel mini-grids. Once this grant funding is exhausted, the development of a business model for private investment is crucial for the sustainability of solar energy retrofitting and other solar projects in Egypt.

The Green Tourism Unit (GTU) of the Ministry of Tourism of Egypt has also designed a support program to provide interest-free loans for hotels in off-grid regions of Egypt to receive electricity from PV-diesel hybrid systems. This program aims to mitigate the anticipated sharp increase in the cost of generating electricity from diesel caused by the government's plans to gradually lift fuel subsidies over the next five years. The GTU will use funds allocated by the Ministry of Finance to cover the current difference in generation costs between PV and diesel. Under this program, an independent power producer will sell the hotel owner PV-generated electricity for the same kWh price as diesel. The GTU will cover the cost difference to the IPP until the two generation types reach cost parity once the subsidies are sufficiently removed.

The hotel will flexibly repay the accumulated loan, depending on its occupancy level, by adding a green surcharge of USD 1.00 per occupied room. Therefore, the program ensures that the hotel's income is not impacted. This program is especially attractive to smaller hotels with credit ratings that are too low to qualify for bank loans.

5.4 Key stakeholders

5.4.1 End users

Tourism sector
The level of awareness among end users of the potential of solar retrofitting is relatively high, particularly in the tourism sector. Many hotel owners in Marsa Alam and Hurghada have conducted feasibility studies and solicited offers from hybrid system solution providers to introduce solar energy into their mini-grids. Hotel owners seek solar systems to reduce their operational costs and target environmentally-conscious tourists from Europe.

Political instability, however, has weakened the sector since the revolution in 2011. The high initial capital expenditure of solar systems has prevented many hotel owners from investing in solar energy thus far. Even with a recovery of the sector in the upcoming years, profits are expected to be used for renovating resorts that have been neglected. Without the support mechanism sponsored by the Ministry of Tourism, adoption of solar energy in the tourism sector will remain slow.

Agricultural sector
In the agricultural sector, over a dozen solar pumping projects have been implemented particularly in the reclaimed desert lands to the west of the Nile basin. Other farm owners, particularly large farms exporting to European markets, are at various stages of the solar project development cycle. Their interest in introducing solar energy stems from diesel supply concerns and the push from European supermarket chains to reduce the carbon footprint of imported crops. Particularly diesel supply concerns are the prime motivator, as irrigation deficiencies not only negatively affect the current harvest, but also permanently affect the orchards. Long-term investments into orchards can be totally lost if irrigation deficiencies occur often and over period of time.

Housing and villages
The use of mini-grids is likely to grow for residential use, particularly for housing and villages located away from the national grid. Over the past decade and particularly since the revolution in 2011, Egypt has seen an immense increase in residential construction in and around major cities. The growth of the real estate market is mainly due to the rapid population increase, high urbanization rate and the devaluing of local currency.

Yet, many residential compounds were not able to secure their electricity supply from the national utility EEHC for the planned number of households in the housing development. Many of these housing developments will likely resort to building their own mini-grids, especially when taking into consideration the five-year plan of the Ministry of Electricity and Renewable Energy to increase electricity tariffs by 2019. Heavy electricity consumers who are likely to live in new residential compounds will experience the sharpest increase in tariffs (Table 10). The high costs of grid connection and in-house cabling within the new residential areas further highlight the need for solar energy mini-grids solution.

Table 10 - Electricity price increase for residential consumption

Consumption categories (kWh/Month)	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019
		Piasters/kWh			
0-200	0.16	0.20	0.26	0.31	0.37
201-350	0.24	0.29	0.35	0.45	0.55
351-650	0.34	0.39	0.44	0.50	0.55
651-1000	0.60	0.68	0.71	0.76	0.86
Higher than 1000	0.74	0.78	0.81	0.86	0.86

Although dozens of end users have expressed strong interest in implementing solar retrofits in their facilities, most have not been successful in securing financing for these investments. International financial institutions consider these projects too small for direct financing, and local banks and leasing companies have been reluctant to finance these projects due to unfamiliarity with the technology.

5.4.2 Solution providers

Given Egypt's past experiences with hybrid solar-diesel systems and overall more advanced level in renewable energy development, there are over a hundred solar energy solution providers. These market players have varying levels of technical capacity and field expertise. There are at least four companies whose level of technical capacity may allow them to implement immediate solutions and become market leaders for off-grid solar energy applications.

5.4.3 Government and public agencies

In Egypt, the Ministry of Electricity and Renewable Energy (MOERE) and the Ministry of Agriculture and Land Reclamation (MoALR) are the most relevant public sector stakeholders, as their input is essential for most project procedures. The New and Renewable Energy Authority (NREA) is the main governmental institution for renewable energy in the country. They set technical standards, accredit solar companies and generally work on growing the market for renewable energy in Egypt. EgyptERA, the independent regulator and consumer protection agency, regulates the feed-in-tariff and other IPP–based renewable energy projects. The Egyptian Electricity Holding company (EEHC), the public utility, is responsible for isolated power plants.

The Green Tourism Unit GTU is developing financial incentives for sustainable energy in the tourism sector across Egypt and serves as an example of a public agency that has already demonstrated awareness and willingness to focus on off-grid solar energy solutions.

5.4.4 Development organizations

The donor and international development community in Egypt is the largest of all four countries. Similar to the international financial institutions, there is an important presence of development agencies and international organizations, such as UNDP, GEF, GIZ and USAID. These organizations have introduced a developmental agenda focusing on sustainable development, renewable energy and employment creation, indicating high levels of awareness and willingness to participate in off-grid solar energy projects.

5.4.5 Financial institutions and investors

By virtue of Egypt's large economy and integration into the global market, most international financial institutions (IFI's) are present in the country. These IFI's also show a specific focus on renewable energy projects in Egypt, indicating significant levels of awareness. Most of this focus has been directed towards large-scale renewable energy projects, highlighting a need to raise the profile of investments in off-grid solar energy in remote areas.

Egypt's banking sector is overall liquid and developed, with dozens of banks operating in the country. These banks have access to capital, and while their interest in renewable energy solutions is growing, this has not translated into concrete programs or credit lines for renewable energy projects, particularly for off-grid applications. The limited knowledge of solar PV technologies has prevented private and national banks from investing in renewable energy projects.

However, the European Bank for Reconstruction and Development (EBRD) has launched a new credit line called Egypt Sustainable Energy Financing Facility (EgyptSEFF). The credit line is dedicated to energy efficiency and renewable energy investments in Egypt. It is currently available to clients in Egypt through the National Bank of Egypt (NBE). EgyptSEFF offers a one-stop-shop solution to the nation's energy conscious business community to develop their sustainable energy projects. The maximum loan amount is USD 5 million with a repayment period of up to five years.

EgyptSEFF services many sectors including, but not limited to:

- *Manufacturing*
- *Agribusiness*
- *Tourism*
- *Commercial and administrative buildings*

Initiatives like EgyptSEFF are crucial for the development of the solar energy market in Egypt. National and commercial banks need to gain experience in developing credit lines for renewable energy projects.

6 Country Specific Analysis: Sudan

Table 11 - Key socioeconomic and energy facts for Sudan

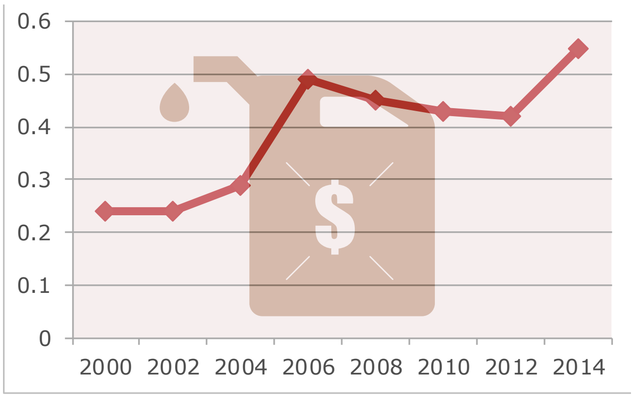
Population	HDI ranking	GDP (USD)	Electrification rate	Diesel price (USD per Liter)
37,960,000 (World Bank, 2013)	**166 out of 187** (United Nations Development Programme, 2013)	**66.57 billion** (World Bank, 2013)	**34.5%** (Arab Union of Electricity, 2013)	**0.51** (World Bank, 2014)

Sudan holds significant potential for decentralized solar PV applications that can bring about significant positive impact to the livelihood of its rural communities. Sudan's low electrification rate (34.5%) indicates that a large segment of the population relies on diesel-based power generation. The largest potential for decentralized solar PV applications lies in the agricultural sector. In Sudan, agriculture employs over 80% of the population and contributes to approximately 30% of Sudan's GDP (2013), making it the primary source of income and employment (United Nations Development Programme, 2015).

Moreover, the steadily rising price of diesel as a result of subsidy removal has been one of the main drivers of high inflation in Sudan, affecting poor farmers in remote areas of the country. In 2012, fossil fuel subsidies accounted for 15% of government expenditure. There has been a steady reduction in subsidies, which has resulted in a 45% increase in diesel price in 2011 and a further 114% price increase in 2013 (United Nations Development Programme, 2015).

Given the importance of the agricultural sector to the overall economy, reducing the cost of energy, particularly for small farmers, will be a major driver of economic growth (United Nations Development Programme, 2015).

Figure 3 - Sudan retail diesel prices (USD/Liter) 2000 - 2014



Despite Sudan's limited past experience with non-hydro renewable energy, there is a growing trend towards increasing the use of solar energy in remote areas, with existing rural electrification solar PV projects amounting to approximately 2 MW in total (Sudanese Ministry of Oil, 2014).

6.1 Diesel consumption trends in remote areas

6.1.1 Utility mini-grids

Hydroelectricity is Sudan's largest source of power, accounting for 80.85% of generation in 2012 (Arab Union of Electricity, 2013). Although power generation has more than tripled since 2000, the majority of Sudanese people are still without access to electricity (U.S. Energy Information Administration, 2014).

The low electrification rate (34.5%) means that a significant portion of the population depends on off-grid generation, mostly biomass and diesel gensets. In order to mitigate the limited reach of the national grid, the Sudanese government has resorted in the past to building isolated mini-grids to supply electricity to major regional cities. Off-grid generation accounted for 2% of the total electricity generation, following major expansions in the national grid (Sudanese Ministry of Oil, 2014). The table below shows some of the major off-grid diesel stations and their capacities (Mahjoub, Restructuring the Sudanese Electricity Sector, 2013).

Table 12 - Isolated diesel power plants in Sudan

Name of station	Capacity (MW)
Port Sudan	24.65
Al-Fashir	10
Al-Geneina	7.8
Kadugli	7.2
Nyala	5
Al-Nahud	4
Al Foula	4
Wadi Halfa	3.3
Al-Daeen	2
Total	63.8

Based on the amount of generated electricity and the average fuel consumption for the specific genset models installed in these off-grid stations, they consume an estimated 40,000 tonnes of diesel per year with estimated CO_2 emissions of 120,000 tonnes (Mahjoub, Power Generation Using Diesel in Sudan, 2013) (Caterpillar, 2013) (MTU, 2014) (MAN Diesel & Turbo).

6.1.2 Private mini-grids

Mines in Sudan have onsite electricity generation using diesel gensets. However, the hybridization potential of private mini-grids for mines, factories and other private installations is difficult to estimate due to a lack of data.

6.1.3 Water pumping for irrigation

In Sudan, agriculture employs over 80% of the population and contributes to approximately 30% of Sudan's GDP (2013), making it the primary source of income and employment (United Nations Development Programme, 2015). Although a significant portion of Sudan's cultivated area depends on rainfall for water, irrigated lands contribute approximately 75% of the added value from agriculture. There are three irrigation systems within the country: pumped, gravity-driven and flood irrigation (United Nations Development Programme, 2015).

The cultivated land area in Sudan ranges between 13 to 17 million hectares based on rainfall intensity and its distribution. In the Northern States of Sudan, the cultivated area is approximately 5.88 million hectares out of which only 5% (273,000 hectares) is pump-irrigated using approximately 25,000 pumps running mostly on diesel. The number of operating pumps will likely increase in the near future as a result of the government's plan to allocate USD 500 million to increase the area of the pump-irrigated land ten-fold (United Nations Development Programme, 2015).

Sudan's estimated diesel consumption for irrigation is shown in Table 13. This estimate is extremely conservative and is mostly based on data from the Northern States. The actual diesel consumption for agricultural pumping is likely to be significantly higher in Sudan, especially when taking into account that large-scale farms outside the Nile Basin has become more common in recent years. More data is needed about diesel consumption of large farms particularly in reclaimed desert areas.

Table 13 - Estimated small-scale water pumping in Sudan

Estimated average operational capacity (kW)	Yearly energy consumption[9] (kWh)	Estimated diesel consumption per kWh (gm)	Estimated number of pumps	Total diesel consumption (000s ti)
4.45	8,010	350	18,154	52

6.2 Market potential for off-grid solar energy

Table 14 – Off-grid solar energy market potential in Sudan

Target applications	Diesel consumption (000s tonnes/year)	Potential PV capacity (MW_p)
Utility mini-grids	40	53[10]
Water pumping in agriculture	52	101[11]

6.3 Barriers and support programs

Despite the existing market potential, the uptake of decentralized solar energy applications in Sudan remains slow. Cost is often cited by stakeholders as the main barrier to scaling up solar energy applications in Sudan. Energy solution providers point to customs duties and taxes on imported solar PV components as the biggest hurdle to wide-scale deployment of this technology in remote areas. In Sudan, border officials estimate customs duties based on their experience with the imported product. Solar PV is a relatively new technology to these officials and reportedly gets taxed up to 60% of the product's price. A solution provider mentioned that he typically pays customs duties of 25-30%, "income" tax of 15-20% and a fluctuating VAT tax. Stakeholders also suggested that foreign currency fluctuations and difficulty in trasporting bulky PV equipment to remote areas make diesel gensets seem comparatively easier and cheaper to use.

Low awareness and negative perception of solar energy technologies pose an important barrier to wide-scale adoption. Interviews with a diverse group of stakeholders revealed a general misunderstanding and distrust of off-grid solar energy applications, which are perceived to be fit only for low-capacity needs such as lighting and water pumping. Lack of well-publicized success stories in Sudan further curtails market trust, in particular among end users and banks. As a result, this information gap causes behavioral barriers and reluctance to try solar energy as an alternative to diesel gensets. In turn, solution providers and financial institutions have come to believe that there is no demand for off-grid solar energy applications.

Interviews with development organizations, end users and solution providers also highlight significant institutional capacity hurdles. According to many stakeholders, inadequate regulations for private sector participation in power generation, excessive red tape and institutional inertia cause significant delays in project implementation, thereby reinforcing the perception that such projects are too complicated to bother with.

Currently, access to financing for solar energy applications is limited in Sudan. Banks prefer to give loans for projects with low-risk profiles and tenors of less than five years, which is not the case with most solar projects. The government does not provide loan guarantees or other financial incentives that will reduce the risk associated with solar energy projects. In addition, banks for the most part lack the capacity to evaluate the feasibility of loans for the installation of solar PV equipment. While most banks in Sudan have microfinance schemes in place, solar energy applications do not currently qualify.

Despite these barriers, the vast majority of stakeholders are aware of the issues associated with widespread usage of diesel gensets and that solar PV technologies represent a suitable alternative to meet the power needs of remote communities. The increase in diesel prices has improved the attractiveness of solar energy retrofitting in most sectors. In fact, some telecom companies have already installed or plan to install solar PV systems for their telecom towers and remote service centers. Tax exemptions, support programs and the introduction of regulations favoring private sector participation can further spur market uptake.

Conducting sector-specific market assessments and showcasing pilot projects and success stories can raise awareness and build trust for actors across the value chain. Ensuring training to government and financial institutions to improve their capacity for assessing project feasibility can be pivotal to fast-track loan approvals. Many stakeholders have pointed towards The National Center for Energy Research (NERC) as a potential hub for training on renewable energy applications, whose role should be strengthened.

6.4 Key stakeholders

6.4.1 End users

End users in Sudan include hotels, small and large farms, mining sites and telecommunications companies. Consultations with these actors confirm that some end users are aware of the benefits of solar PV and willing to switch from diesel. For example, Zain Telecom has installed over 58 hybrid systems that use 40% less diesel in Sudan (Zain, 2011).

In the past, agricultural end users have benefited from awareness-raising activities to promote solar pumping. Given the importance of this sector in Sudan, UNDP is currently developing a GEF-funded project to encourage the use of solar pumping in the northern region through pilot projects and accessible financing. Such projects serve to reduce the country's carbon emissions, as the agricultural sector has the largest share of CO_2 emissions in Sudan compared to the energy, industrial, land use, forestry and waste sectors. In 2000, the emissions from agricultural sector represented approximately 74% of total emissions produced in the country (United Nations Development Programme, n.d.).

6.4.2 Solution providers

Sudan has a number of local solution providers, predominantly based in Khartoum, that have past experience in off-grid solar energy applications and existing operations in remote areas. These solution providers have implemented solar PV projects for a wide range of customers including farm owners, manufacturers, government entities and international organizations active in Sudan. The presence of these experienced companies in the market will facilitate its expansion in the future. Training in business development and business model design will enhance these companies' ability to expand their reach.

6.4.3 Government and public agencies

In Sudan, the most relevant public sector actors are the Ministry of Water Resources and Electricity, responsible for developing and implementing policies for energy and electricity, and the Ministry of Agriculture and Natural Resources. The Ministry of Finance and National Economy provides funding for solar energy projects and the Ministry of Investment is pivotal for customs and land issues relating to solar equipement and projects. The latter created a rural electrification program that targets solar pumping applications among other renewable energy technologies. The National Center for Energy Research (NERC) organizes capacity building activities and provides policy advice in the field of renewable energy. Because diesel-based power generation is widespread in various sectors, consultations and engagement with these ministries will be necessary to pave the way for solar energy adoption in Sudan.

6.4.4 Development organizations

Sudan has many international development projects targeting rural electrification and development that include sustainable energy components. Organizations such as UNDP, the Global Environment Facility (GEF) and Practical Action are active in projects related to solar water pumping in particular. The UNDP has developed a project to promote the use of solar water pumps for irrigation in Sudan with funds from the GEF.

6.4.5 Financial institutions and investors

Sudan's banking sector consists of 35 banks and is mostly dominated by large banks with more than USD 17 billion in outstanding loans and advances (Global Impact Investing Network, 2015). Commercial banks represent around 97% of the financial system, based on total assets. The government-owned banks include three specialized financial institutions (SFIs), jointly owned by the Central Bank of Sudan (CBOS) and Ministry of Finance and mandated to fill specific access-to-finance gaps. The three SFIs are the Agricultural Bank of Sudan (ABS), the Industrial Development Bank and the Savings and Social Development Bank (SSDB). The ABS supplies about 53% of the bank financing of the agricultural sector, and the SSDB specializes in supporting microfinance activity.

Sudan's banking system follows Islamic Sharia law, which prohibits charging interest on debt. Instead, the banking sector relies on partnership and risk sharing (Global Impact Investing Network, 2015). Frequently used financial products include Mudarabah (passive partnership), Musharakah (active partnership), Murabaha (sale contract at a profit markup) and Salam (forward sale contract).The microfinance sector is small but growing because the government actively promotes its development.

Banks consulted in this study include Farmer's Commercial Bank that targets the agricultural sector, the Al Nile Bank for Commerce and Development, Bank Al Baraka, Bank Al Ousra, Saving and Social Development Bank and Sudanese Egyptian Bank. Most of the bank officials interviewed expressed concerns regarding financing solar energy applications based on perceived low return on investments, little past experience with successfully financed solar energy projects and weak in-house capacity to evaluate project feasibility.

7 Country Specific Analysis: Yemen

Table 15 – Key socioeconomic and energy facts for Yemen

Population	HDI ranking	GDP (USD)	Electrification rate	Diesel price (USD per Liter)
25,956,000 (Central Statistical Organization, 2014)	**154 out of 187** (United Nations Development Programme, 2013)	**35.95 billion** (World Bank, 2013)	**40%** (United Nations Development Programme, 2014)	**0.70**[12] (Yemen Petroleum Company, 2015)

Yemen's low access to electricity and heavy reliance on isolated diesel generation makes it a promising candidate for off-grid solar energy retrofitting. Yemen's population suffers from low access to electricity, with only 40% of the population connected to the grid. Inequalities in terms of access exist among rural and urban households and businesses. Although 75% of the population is regarded as rural, only 23% of the rural population has access to electricity, compared to about 85% of the urban population.

Figure 4 - Yemen retail diesel prices (USD/Liter) 2000 - 2014

Almost half of the population relies on electricity from private diesel gensets (United Nations Development Programme, 2014). The reliance on diesel has become problematic as a result of supply shortages and increasing diesel retail prices. Diesel shortages have been exacerbated by the ongoing violence in the country. According to RCREEE contacts in the Rural Cities Electricity Administration, most off-grid generating stations only receive enough diesel fuel to generate electricity at night, if any supply at all. Retail diesel prices have increased ten-fold since 2000 as a result of subsidy removal.

Yemen's solar energy potential is vast. In 2014, UNDP estimated Yemen's solar technical potential around over 18,000 MW with two of the most feasible applications being rural electrification and solar water pumping (UNDP, 2014).

7.1 Diesel consumption trends in remote areas

7.1.1 Utility mini-grids

In general, electricity supply in Yemen is limited. The weak generation capacity, high grid losses and increasing demand are among the top challenges for the energy sector (United Nations Development Programme, 2014). To mitigate the limited reach of the national grid, the national utility owns and leases diesel-based power stations to supply isolated areas with electricity, with an estimated diesel consumption of 223,000 tonnes per year.

Utility-owned isolated stations

The Public Electricity Corporation owns and operates a number of isolated stations distributed in several regions of the country. The following table shows estimates regarding the consumption of public off-grid stations in Yemen (Public Electricity Corporation, 2014):

Table 16 - Utility-owned isolated diesel power plants in Yemen

City	Average load (MW)	Annual energy production (MWh)	Annual diesel consumption (ktoe)	Average diesel consumption (liter/kWh)
Al-Rayyan	3.8[14]	28,296[15]	5.76	0.248
Al-Monawwara	4.22	6,741	1.82	0.231
Khalaf	2.48	6,010	1.54	0.270
Al-Shehr	1.24	8,012	1.1	0.264
Seiyun	NA[16]	62,513	14	0.263
Socotra	1.18	5,863	1.3	0.228
Hajja	2.48	6,068	1.49	0.287
Al-Bayda	1.22	4,316	1.07	0.290
Al-Hodeida	1.69	5,332	1.39	0.305
Al-Mahra	3.36	14,882	3.53	0.277
Shabwa	2.93	17,843	3.97	0.260
Lahjj	2.58	10,059	2.55	0.296
Sa'da	2.09	34,778	8.52	0.287
Total	**-**	**210,713**	**48**	-

Utility-leased isolated stations

To fill the gap between supply and demand, the Ministry of Electricity and Energy leases power stations from private companies such as Aggreko, Al-Ahram, Saqr, Belhamad and Aden for Iron. The leased stations supply electricity either on-grid or off-grid, and the government provides these stations with diesel fuel. The following table shows estimates regarding the consumption of leased off-grid stations in Yemen (Public Electricity Corporation, 2014):

Table 17 - Utility-leased diesel power plants in Yemen

Governorate	Purchased energy (MWh)	Annual diesel consumption (ktoe)	Average diesel consumption (liter/kWh)
Al-Mahra	62,776	14.7	0.274
Al-Bayda	28,849	6.96	0.273
Coast of Hadhramaut	224,551	55.71	0.280
Al-Wadi	31,264	7.78	0.281
Shabwa	114,229	27.85	0.271
Lahjj	19,910	5.23	0.297
Mareb	235,132	57.62	0.277
Total	**716,741**	**175.85**	**0.273**

7.1.2 Private industrial facilities

The national grid of Yemen frequently experiences power outages and supply intermittency. As a result, most industrial facilities remain isolated from the network and consume a large amount of diesel to generate electricity onsite. One of Yemen's largest industrial/commercial groups occupies the largest share in the industrial sector in Yemen. According to RCREEE contacts at this group, the estimated on-site generation capacity of the group's factories and malls is around 126 MW. The stations are estimated to consume 78,000 tonnes of diesel annually. Diesel is provided to the industrial sector at a price of 150 Riyals per liter, or USD 0.70 per liter.

7.1.3 Single-activity applications

The most prevalent single-activity application for diesel gensets is in the telecommunication sector. Two companies dominate this sector. MTN has the largest number of off-grid towers in Yemen, followed by Y. The following information was collected during interviews regarding diesel consumption in off-grid telecom towers.

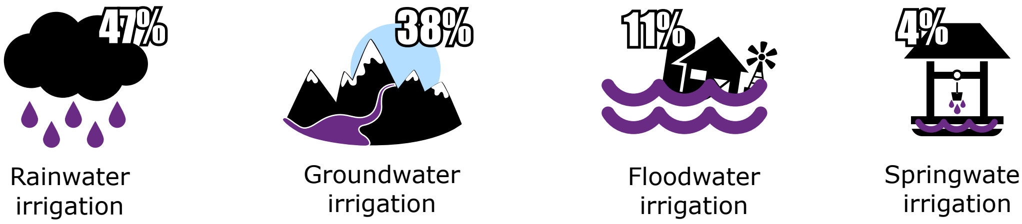
Table 18 - Diesel consumption in Yemen's telecom industry

Company	Number of off-grid towers	Average genset capacity (kVA)	Annual diesel consumption (ktoe)
MTN	680	15	15.35
Y	20	14	0.6
Total	**700**	**-**	**15.95**

7.1.4 Water pumping for irrigation

According to the Ministry of Agriculture's 2012 annual report, the cultivated land ratio declined compared to the previous years, due to lack of rain and diesel shortages brought about by the country's political crisis. Another important factor is the removal of of the subsidy on diesel, with prices reaching USD 0.7 per liter in 2015. This indicates great potential for solar energy retrofitting, which will prove beneficial to this economically-significant but energy-intensive sector. Many farmers reportedly left their lands uncultivated due to diesel shortage and high black market prices.

Yemen's land area is 45,550,246 hectares, with only 3.01% cultivated, equivalent to about 1.4 million hectares. Irrigation in Yemen depends on 4 main sources of water, mapped by percentage of agricultural area as follows (Ministry of Agriculture and Irrigation, 2012):



For irrigation by groundwater, farmers rely on diesel-based pumps to draw water from the aquifers through wells. An estimated 70,000 active diesel pumps were operational in Yemen in 2009, pumping from a variety of wells with a wide range of depths (World Bank, 2015). The following table shows the estimated diesel consumption in groundwater pumping (Ministry of Industry and Trade, 2015):

Table 19 - Estimated diesel consumption figures for groundwater pumping in Yemen

Area	Annual groundwater withdrawal (billion m³)	Specific diesel consumption (liters/m³)	Annual diesel consumption (ktoe)
Highlands	1.6	0.75	1,026
Coastal areas	1.4	0.43	514.7
Eastern Plateau	0.6	0.21	107.73
Total	**3.6**	**-**	**1,648.43**

7.2 Market potential for off-grid solar energy

Table 20 – Off-grid solar energy market potential in Yemen

Focus area	Diesel consumption (ktoe/year)	Potential PV capacity (MW_p)
Utility mini-grids	48	63[17]
Private mini-grids	254.29	293[18]
Water pumping	1,648.43	894[19]
Single-activity applications	15.95	5[20]

7.3 Barriers and support programs

The ongoing violent conflict in Yemen is the greatest barrier to wide-scale uptake of solar energy technologies in off-grid areas. Faced with the physical and financial insecurities, businesses are less likely to make long-term capital investments. Although in the long-run solar energy is a more resilient form of technology to withstand armed conflict, it would be difficult to import, transport and install solar PV system under the current political and security conditions in Yemen.

In 2014, UNDP piloted a project for solar water pumping in coastal plain farmlands, specifically in Hadhramout, Abyan and Tehama. This pilot project revealed a number of barriers that hinder the sustainable development of solar water pumping in Yemen, such as lack of supportive policy frameworks and practical market-based business models, compounded by relatively high upfront capital cost of solar PV technologies. Moreover, the high prevalence of poverty, proliferation of low-quality PV equipment and lack of awareness have reduced the pace of solar market expansion in Yemen (United Nations Development Programme).

The Yemeni government introduced a rather successful incentive program for solar pumping shortly before the outbreak of the conflict in early 2015. The Agriculture and Fisheries Production Promotion Fund, in collaboration with CAC Bank, introduced an interest-free loan program for farmers. This program enables them to purchase solar-powered pumps, for which demand is increasing noticeably, to replace diesel-powered ones, as part of a government program to mitigate the negative effects of diesel fuel subsidy cuts.

According to RCREEE contacts at CAC Bank, the bank administers the interest-free loans to farmers to purchase solar-powered pumps, while the government covers loan service fees. The government also provides grants depending on the loan's repayment period, as follows:

20%
grant no loan is taken and cost is paid in cash

15%
grant if the loan is repaid in installments over a period of 12 months

10%
grant if the loan is repaid in installments over a period of 24 months

The program has been implemented and 170 pumps were financed so far. Public and private sector stakeholders have, however, reported that only prominent and wealthy farmers or agribusiness investors were able to benefit from this program. This is mainly due to the large loan guarantees required by the bank, which renders the program inaccessible to financially-strained farmers. CAC Bank only funds eligible projects to pumping depths of less than 500 meters, as it was deemed infeasible otherwise.

Through the Small Enterprises Development Fund, the Ministry of Industry and Trade has also started financing solar energy projects in late 2014, with five suppliers of PV equipment signed up for the program as of April 2015. The loan has a repayment period of three years and an annual interest rate of 12.5%. The features of this loan program are not significantly different from the 13.5% interest rate and the two-year disbursement period for other projects.

7.4 Key stakeholders

7.4.1 End users

Many of the end-users that were interviewed for this study seemed to have a basic understanding of renewable energy, especially farm owners and commercial users. These users expressed interest in exploring the possibility of introducing solar technologies into their facilities. Some went as far as asking the study team for technical assistance in soliciting and evaluating technical and financial offers from solar energy solution providers.

7.4.2 Solution providers

Due to increasing insecurity of diesel supplies and electricity blackouts, Yemen has seen a market increase in the number of solution providers. However, most of these solution providers are focused on small applications and typically act as import agents of large international manufacturers. They do not necessarily have the technical capacity to implement the types of projects that would be required for off-grid solar energy retrofitting in remote areas. These solution providers would need significant technical capacity building. The status of these companies since the breakout of the conflict is unknown.

7.4.3 Government and public agencies

In Yemen, the most relevant public sector actor is the Ministry of Electricity and Energy with its General Rural Electricity Authority and Renewable Energy Department, responsible for developing and implementing policies in the fields of energy and electricity. The General Rural Electricity Authority focuses on targeted rural electrification and development. The Ministry of Agriculture and Irrigation is responsible for developing and implementing policies in the fields of agriculture and irrigation, with past experience in solar water pumping programs. The Ministry of Industry and Trade's Small Enterprises Development Fund provides funding for diverse solar energy projects.

7.4.4 Development organizations

Prior to the outbreak of armed conflict in Yemen, many international development organizations were active in the field of solar energy promotion in Yemen. These organizations include UNDP, GIZ, World Bank, USAID and OFID. Under the current conflict situation, the focus of development organizations has shifted to humanitarian assistance and conflict mitigation for the foreseeable future. This shift in focus should not prevent these organizations from integrating solar energy applications into their operations, such as powering clinics and other essential facilities in refugee camps. Solar energy applications should also be taken into account when planning for post-conflict reconstruction.

7.4.5 Financial institutions and investors

Given Yemen's ongoing issues, the banking sector is not as developed as in the other countries. While the Cooperative and Agricultural Credit Bank (CAC) has gained significant experience in solar pumping funding as discussed in previous section, the rest of the banking industry has little experience in funding renewable energy projects. The banking sector has likely sustained significant damage during the conflict.

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Appendix A

Methodology for estimating potential PV capacity (electricity generation)

A.1 Djibouti

(Parsons Brinckerhoff, 2009) presented the following information about the Tadjoura and Obock power plants:

Table 21 - Generation projections for the Tadjoura and Obock power plants

Tadjoura			Obock		
Installed capacity (MW)	Projected demand for 2015 (MW)	Projected energy generation for 2015 (GWh)	Installed capacity (MW)	Projected demand for 2015 (MW)	Projected energy generation for 2015 (GWh)
2.2	**1.37**	**5.081**	**1.4**	**0.6**	**2.844**

The Tadjoura power plant is, therefore, loaded at around 62.3% of its capacity, while Obock is loaded at only 42.9% of its capacity. For efficient operation, a diesel genset cannot run on less than 40% of its installed capacity (SMA, 2015).

If all the gensets at Tadjoura and Obock are running (i.e. no backup gensets), solar PV penetration can only cover 22.3% of the generation in Tadjoura and 2.9% of the generation in Obock. At Djibouti's average specific annual yield of 1,908 kW_h/kW_p (SMA, 2015), the Tadjoura and Obock plants can be hybridized with 655 and 45 kW_p of PV, respectively, or 700 kW_p in total.

A.2 Egypt

Utility-owned mini-grids

Based on the geographic locations of the isolated stations, the average PV specific annual yield for each of the DCs was estimated (Solar-Med-Atlas, n.d.). Table 22 shows the estimated potential PV capacity, based on a maximum energy generation share of 60% (SMA, 2015).

Table 22 - Potential PV capacity for each of the DCs operating isolated diesel power plants.

Distribution company	Annual energy generation (GWh)	Potential annual PV energy generation (GWh)	Average specific annual yield (kWh/W_p)	Potential PV capacity (MW_p)
Canal	184.7	110.82	1,787	62
El Behera	30.7	18.42	1,743	10.6
Middle Egypt	24.3	14.58	1,843	8
Upper Egypt	4[21]	2.4	1,760	1.4
Total	**243.7**	**146.22**	**-**	**82**

Privately owned mini-grids

Based on a survey conducted by RCREEE in Marsa Alam, and taking into account the different scales of and levels of service in the participating hotels, an annual average electricity consumption figure of 19,576 kWh per hotel room was yielded by the ensuing feasibility study.
For a minimum of 12,500 hotel rooms in Marsa Alam (Tripadvisor, n.d.), the total annual electricity demand is estimated to be 244.7 GWh. At a PV share of 60% and a specific annual yield of 1,900 kWh/kW_p (Solar-Med-Atlas, n.d.), the potential PV capacity is around 77.3 MW_p.

A.3 Sudan

For the areas where isolated diesel power plants are located in Sudan, the average specific annual yield for PV is approximately 2,073 kWh/kW_p (SMA, 2015). For a 60% PV share (SMA, 2015) in the total off-grid energy generation of 183 GWh, the potential PV capacity is approximately 53 MW_p.

A.4 Yemen

Utility-owned stations

Due to the relative lack of PV-specific meteorological data and measurements, the average specific annual yield for San'aa (1,979 kWh/kW_p) (SMA, 2015) was used to estimate the potential PV capacity for all off-grid stations. Table 23 shows the estimated potential PV capacity, based on a maximum energy generation share of 60% (SMA, 2015).

Table 23 - PV potential for utility-owned stations in Yemen

City	Average load (MW)	Annual energy production (MWh)	Potential annual PV energy generation (MWh)	Potential PV capacity (MW_p)
Al-Rayyan	3.8	28,296	16,978	8.58
Al-Monawwara	4.22	6,741	4,045	2
Khalaf	2.48	6,010	3,606	1.82
Al-Shehr	1.24	8,012	4,807	1.1[22]
Seiyun	N/A[23]	62,513	37,508	18.95
Socotra	1.18	5,863	3,518	1.78
Hajja	2.48	6,068	3,641	1.84
Al-Bayda	1.22	4,316	2,590	1.3
Al-Hodeida	1.69	5,332	3,199	1.62
Al-Mahra	3.36	14,882	8,929	4.51
Shabwa	2.93	17,843	10,706	5.4
Lahjj	2.58	10,059	6,035	3
Sa'da	2.09	34,778	20,867	10.54
Total	**-**	**210,713**	**126,428**	**63**

Utility-leased stations

Similarly, Tables 24 show the estimated potential PV capacity for utility-leased stations.

Table 24 - Potential PV capacity utility-owned stations in Yemen

Governorate	Purchased energy (MWh)	Potential annual PV energy generation (MWh)	Potential PV capacity (MW_p)
Al-Mahra	62,776	37,666	19
Al-Bayda	28,849	17,309	8.75
Coast of Hadhramaut	224,551	134,731	68
Al-Wadi	31,264	18,758	9.48
Shabwa	114,229	68,537	34.63
Lahjj	19,910	11,946	6
Mareb	235,132	141,079	71.29
Total	**716,741**	**430,026**	**217.15**

Private Mini-grids

Table 25 shows the estimated potential PV capacity the aforementioned industrial group's power stations

Table 25 - Potential PV capacity for the industrial group's factories in Yemen

Factory	Generation capacity (MW)	Potential PV capacity (MW_p)
Total	**126**	**75.6**

Single-activity electricity generation

Based on the data provided by telecom operators in Yemen, PV potential is estimated based on the number of off-grid towers and the average generator power for each company. Assuming a 60% PV share and a generator power factor of 0.8 (Caterpillar, 2013) (MAN Diesel & Turbo) (MTU, 2014) (SMA, 2015), Table 26 shows the estimated PV potential in the Yemeni telecom industry.

Table 26 - Potential PV capacity in the Yemeni telecom industry

Company	Number of off-grid towers	Average genset power (kW)	Total genset power (MW)	Potential PV capacity (MW_p)
MTN	680	12	8.2	4.92
Y	20	11.2	0.22	0.132
Total	**700**	**-**	**8.44**	**5**

Appendix B

Methodology for estimating potential PV capacity (water pumping)

B.1 Djibouti

At Djibouti's average well depth of 72 m (Houssein & Jalludin, 1996) and 6.19 daily peak sun hours as an annual average (Sougal, Pon, Bates, & Petersons, 2009), most modern submersible electric pumps would have an average pumping rate of 14 m^3 per day per kW of motor power (Pentair Water).

Assuming Djibouti's average daily groundwater withdrawal is 5479.45 m^3 (see section 4.1.3), the average total electric pumping capacity throughout the country would amount to 392 kW. This is equivalent to a PV capacity potential of 500 kW_p in total, to account for variations in solar irradiation and other losses (New York State Energy Research and Development Authority).

B.2 Egypt

Based on the data provided by the Ministry of Agriculture, the total non-portable (on-grid and off-grid) electrical pumping power can be estimated as shown in the following table:

Table 27 – Estimated fixed irrigation pumping power in Egypt

Pump size (kW)	Number of pumps	Total pumping power (kW)
7.5	66,697	500,227
14.25	60,309	859,403
26.25	19,423	509,853
37.5	19,178	719,175
Total	**165,607**	**2,588,658**

Assuming a PV generation share of 60% (SMA, 2015), the total potential PV share of non-portable diesel pumping power is approximately 1,550 MW, which requires an approximate PV capacity of 1,938 MW_p in total, to account for variations in solar irradiation and other losses (New York State Energy Research and Development Authority).

B.3 Sudan

In section 6.1, the estimated total pumping power of diesel pumps is 80.8 MW. The use of electrical pumps of the same power would require an approximate PV capacity of 101 MW_p in total, to account for variations in solar irradiation and other losses (New York State Energy Research and Development Authority).

B.4 Yemen

Accounting for the difference in the annual average peak sun hours between Yemen and Djibouti (6.12 for the former and 6.19 for the latter), an estimated pumping rate of 13.8 m^3 per day per kW of motor power can be used for the purpose of this analysis.

Assuming Yemen's average daily groundwater withdrawal is 9,863,014 m^3 (see section 7.1.4), the average total electric pumping capacity throughout the country would amount to 714.7 MW. This is equivalent to a PV capacity potential of 894 MW_p in total, to account for variations in solar irradiation and other losses (New York State Energy Research and Development Authority).

Endnotes

1. *Solar fraction is the ratio of the amount of input energy contributed by a solar energy system to the total input energy required for a specific application.*
2. *See Appendix A for methodology.*
3. *See Appendix B for methodology.*
4. *Assuming the pumps operate for 20 hours per day and 300 days per year (6,000 hours per year).*
5. *See Appendix A for methodology.*
6. *See Appendix A for methodology.*
7. *See Appendix B for methodology.*
8. *To exclude South Sudan and the areas irrigated by gravity, an irrigated area of 400,000 hectares (half of Aquastat's figure) was assumed for the purpose of this analysis.*
9. *Assuming the pumps operate for 12 hours per day and 150 days per year (1,800 hours per year).*
10. *See Appendix A for methodology.*
11. *See Appendix B for methodology.*
12. *This pump price does not apply to utility-operated or privately operated generating stations. According to the Yemen Petroleum Company, generating stations buy diesel at a subsidized price of USD 0.186 per liter.*
13. *Al-Rayyan station is primarily operated by HFO, but includes a sizeable installed capacity of diesel gensets.*
14. *The average station load is 29.84 MW. The above figure was estimated based on comparing the shares of diesel and HFO in electricity generation.*
15. *Total energy production for the station is 222,782 MWh. The above figure was estimated based on comparing the shares of diesel and HFO in electricity generation.*
16. *Maximum load is 30 MW for this station.*
17. *See Appendix A for methodology.*
18. *See Appendix A for methodology.*
19. *See Appendix B for methodology.*
20. *See Appendix A for methodology.*
21. *Estimated based on installed capacity.*
22. *Estimated as 60% of the 1.8-MW maximum load (Public Electricity Corporation, 2014).*
23. *Maximum load is 30 MW for this station.*

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