ASSESSMENT OF THE STATUS OF SOLAR PV IN YEMEN

World Bank Project: Republic of Yemen
Restoring and Expanding Energy Access

RCREEE

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

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About RCREEE

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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Table of Contents

List of Figures

List of Tables

Acronyms

AGM	Absorbent Glass Mat
Ah	Ampere hour
CAC	Cooperative and Agricultural Credit
DC	Direct Current
AC	Alternative Current
DoD	Depth of Discharge
FiT	Feed-in Tariff
I_{sc}	Short Circuit Current
I_{mp}	Ampere at Maximum Output
IEC	International Electrotechnical Commission
kW_p	Kilowatt Peak
LCD	Liquid Crystal Display
MPPT	Maximum Power Point Track
MW	Megawatt
PV	Photovoltaic
PWM	Pulse Width Modulation
STC	Standard Testing Condition
A	Ampere
SEDF	Small Enterprise Development Fund
W_p	Watt peak
USD	United States Dollar
V_{oc}	Open Circuit Voltage
V_{mp}	Voltage at Maximum Output
YER	Yemeni Rial
GARE	General Authority for Rural Electrification
EC	European Conformity
ICF	Internal Collateral Fund
IFIs	International Financial institutions
TUV	Technischer Überwachungsverein (Technical Inspection Association)
SME	Small and Medium Enterprise
USAID	United States Agency for International Development

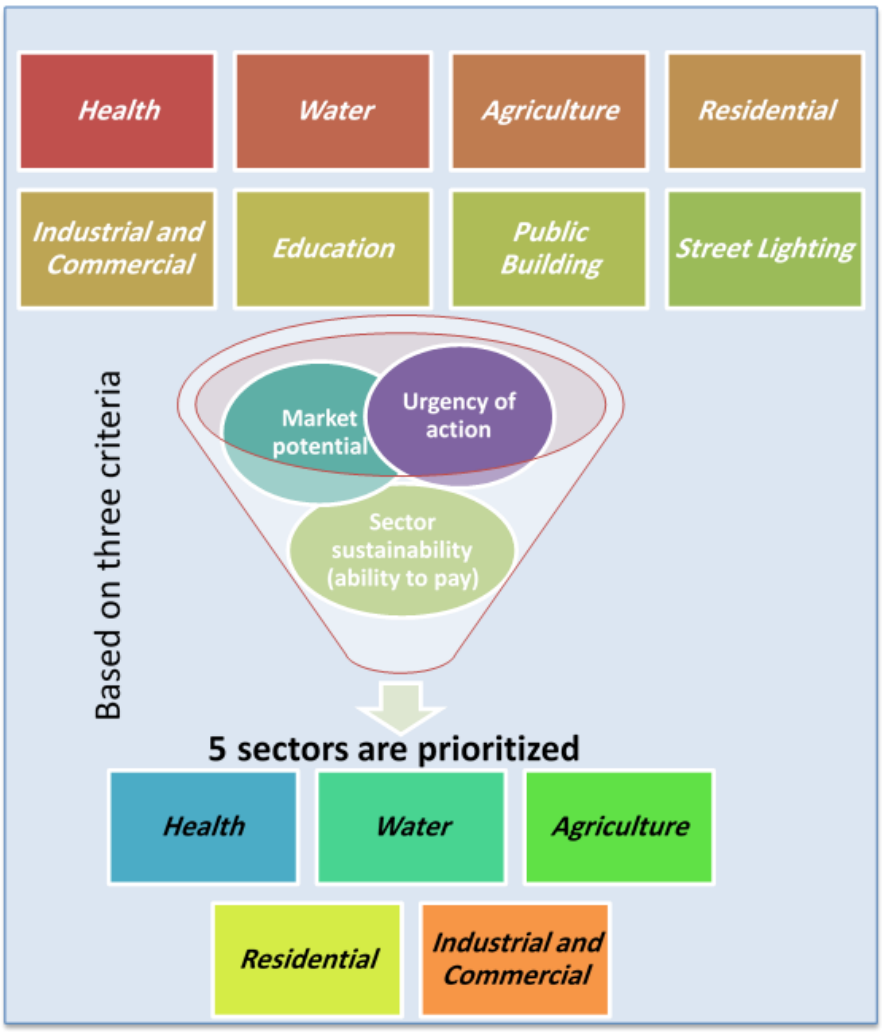
Executive Summary

The Republic of Yemen (henceforth referred to as Yemen) is one of the poorest countries in the MENA region yet with a rich endowment of renewables. The country has been undergoing political and economic unrest that negatively affects its energy sector and particularly leads to drastic electricity cutoff across the whole country. This challenging situation has geared the Yemeni society towards resorting to reliance on solar photovoltaic (PV) as a survival solution to meet their basic electricity needs. PV technologies have growingly penetrated the market as the only way to get electricity in certain areas for both off-grid communities as well as groups affected by recurrent power shortages and as a new alternative to the expensive and often unreliable diesel-based small independent power producers. This has been fostered by the potential of solar PV technology to enhance the social and economic conditions in the country as well as the dramatic reduction in the prices of the technology of concern.

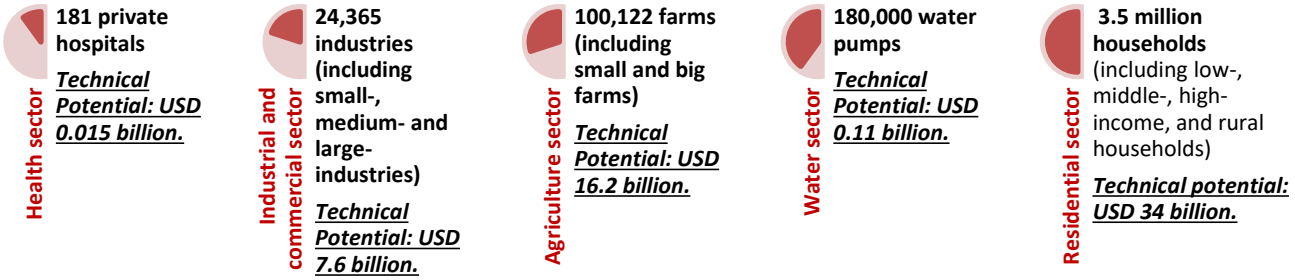
This report first describes briefly the electricity profile in Yemen. Next, it digs deeper into eight vital dynamic sectors in Yemen to estimate the technical potential, and assess PV application specifically, and energy aspects generally. Then, the report discusses the already existing financing mechanisms of PV projects, and points out to the major challenges faced. To address these challenges, three main business models are proposed. Following, the report portrays the existing supply chain of the PV market in Yemen, and details more on the technical specification and cost of technologies of PV systems (PV panels, batteries, etc.) available in Yemen. Finally, several recommendations are outlined based on the acquired knowledge and information.

Accessing reliable data for a country in a situation of fragility such as the Yemeni case is often one of the major challenges for the development of a report aiming at providing a realistic picture of the prevailing situation. On the initial phase, general and specific information about the actual current situation in Yemen has been collected from governmental and international reports and statistics as well as newspapers and other media forms. A significant part of the gathered information has then been obtained by undertaking local interviews and distributing questionnaires among an extensive variety of stakeholders from the PV sector in Yemen, from retailers to private and public consumers, passing by importing companies, NGOs, designers, technicians, bankers, and government officials.

To provide a reliable foundation for this study, *eight sectors* have been investigated which are: Agriculture, Water, Health, Industrial and Commercial, Residential, Education, Street Lighting, and Public Buildings. Assessment and prioritization of these sectors were conducted based on three main criteria: 1) Market Potential, 2) Urgency of Action and 3) Sector Sustainability (ability to pay). Based on these criteria, *five sectors* are prioritized: Water, Health, Agriculture, Industrial and Commercial, and Residential.



The report highlights that, over the last five years, around USD 1 billion has been invested in solar PV systems for the residential sector—estimate of the market penetration of PV systems was found at around 75% of households in urban areas and 50% in rural areas. This signals a booming potential not only in the residential sector, but also in other dynamic sectors. Estimates of market technical potential in important sectors, shown below, give promising figures for further deployment and expansion in the PV market in Yemen, which could trigger a multibillion market, sustaining the PV business for at least two decades to come. Nonetheless, certain assumptions were considered when developing the technical potential, and that the actual potential could be, to variable degrees, less than the stated figures.



Notwithstanding the flourishing market of PV in Yemen, PV market still suffers from several challenges, for instance: improper system design, and lack of the technical awareness about the product's quality and specifications. A clear example of these challenges is the use of car batteries in the solar PV system to store energy, which is considered the main reason for system failures in Yemen.

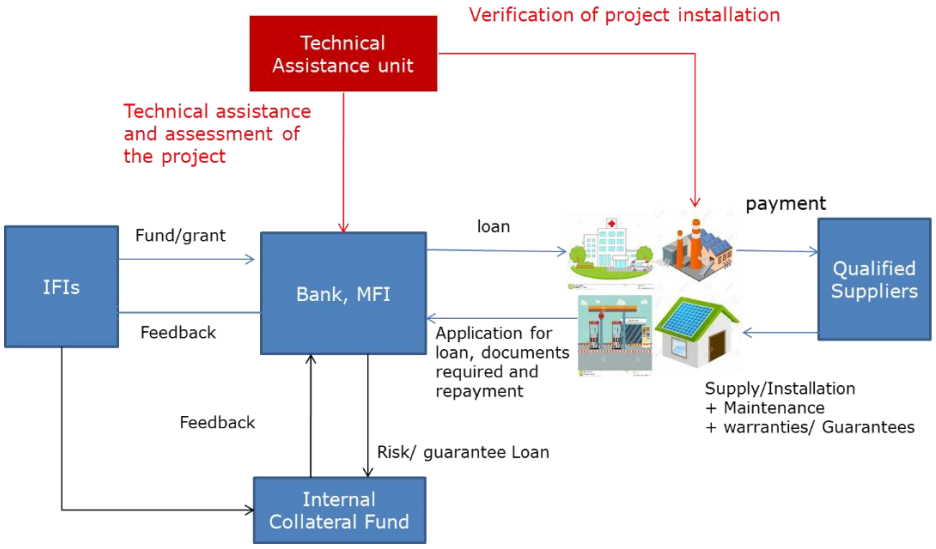
The Yemeni market is characterized by a large share of imported solar system components from Asian manufactures with minor imports from other countries, such as Germany and the USA. It is mainstreamed by the preference of low quality but more affordable products rather than high-quality products requiring higher (and often unaffordable) investment costs. Misled choices on the side of consumers are the consequence firstly, of this priority setting and secondly, the general lack of basic knowledge on the features and properties of the technology. Developing the knowhow among the population could further avoid poor investment choices. The low quality of products and improper design, installation, operation, and selection of equipment are the main factors affecting the system's reliability.

Another key challenge is the stringent conditions of granting loans for the average community classes. Despite the existence of several financial institutions willing to provide credits for solar PV projects, these are often mainly targeted at governmental employees and customers who are able to provide guarantees, which mass consumers often lack. This challenge is interlinked a lot to the augmentation of the trend towards low quality but affordable solar systems, and if not properly handled, it may lead to market failure.

To tackle the challenge of guarantee requirement, three primary financing business models have been developed to fit into the Yemeni context. These are: Internal Collateral Fund (ICF), Aggregator Principle, and My Solar PV.

Internal Collateral Fund (ICF)

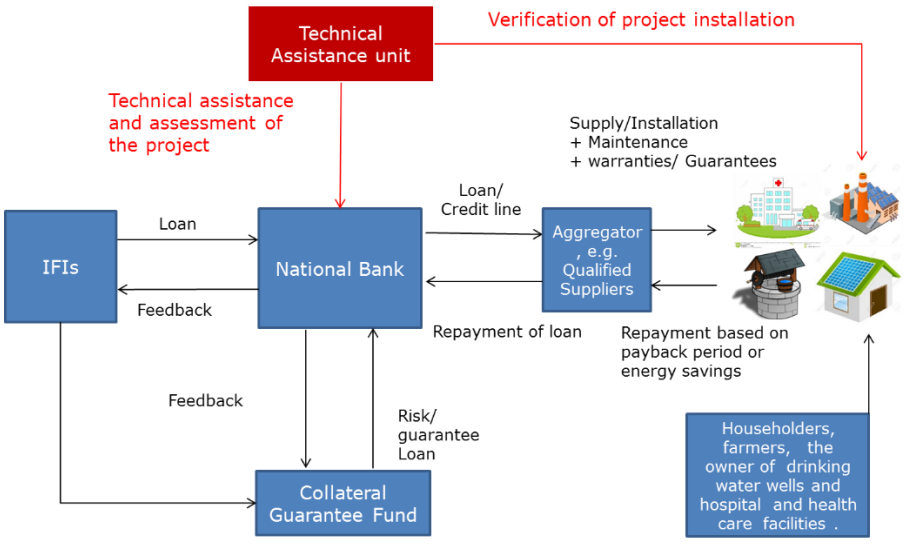
- In this model, an insurance-like entity is to be established (that is ICF), and should be affiliated to and managed by a local bank. The IFI's role is providing financial support in form of credit line to this entity which in turn will cover a certain percentage.
- For the borrowers to benefit from this service, they will have to pay a certain service fee to the ICF.



Block Diagram of Internal Collateral Fund (ICF) business model

Aggregator Principle

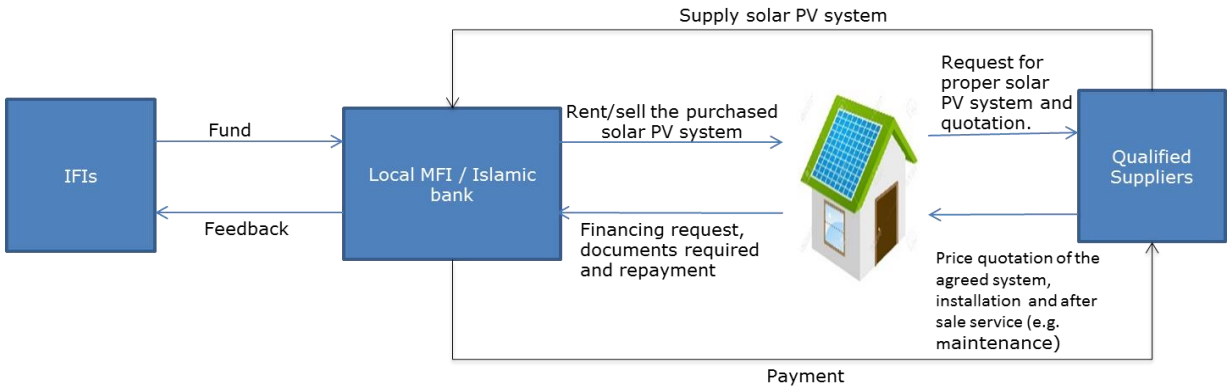
- The Aggregator principle relies on the idea of empowering big entities and/or clients with a strategic position in the market that can serve as an "Aggregator" of smaller beneficiaries to achieve economies of scale. Examples of such entities may include PV suppliers, energy cooperatives, community service organizations (for instance, a farmers' cooperatives).
- The potential beneficiaries should provide acceptable guarantees to the aggregator who would be fully responsible to provide the necessary guarantee required by the local bank– thus both the IFI and the local bank will take no risk.



Block diagram of Aggregator Principle business model

My solar PV

- Considering the fact that the Islamic Sharia —which is of paramount significance in Yemen— is to a great extent understood as advising people to avoid taking interest-based loans, this model aims to provide clients with a solar PV system itself rather than the capital needed to purchase it in order to circumvent the "charging of fees for incurred debt". In other words, the local bank purchases the solar PV system and then rents/sells it to the end-users at an ex-ante amount of money that is inclusive of the system's capital and a certain profit.
- The local Islamic bank/MFI also manages the loans to, and deal with the beneficiaries (e.g. households). The required guarantees by the bank would follow the same conventional rules.



Block diagram of My Solar PV business model

Among the key identified findings during the study is the clear lack of supporting policies, such as feed-in tariffs and net metering policies, for the connection of solar PV systems to the grid in Yemen. Questions remain whether such policies would be applicable in the current Yemeni context or should it be left to the longer term when stability is achieved, even partially.

The derived results of the analysis have been translated into a set of recommendations to be applied by both relevant decision-makers in Yemen as well as stakeholders, such as international financial institutions, willing to actively get involved in the empowerment of the solar PV sector in the country. These recommendations can be summarized in three categories: those of regulatory nature; special programs targeting financial mechanisms and the provision of capacity building initiatives; and the development of appropriate institutional frameworks.

As an outlook of the results it shall be mentioned here that among the formers, and given the importance of the importation of solar PV components in Yemen, customs and tax exemptions are presented as a key step to proceed with the strengthening of the sector, as well as the undertaking of deep subsidy reforms of the electricity tariffs. In a mid-term base, quality assurance and market surveillance mechanisms should be enforced in order to provide consumers with long-term savings coming from the avoidance of misled decisions regarding

system quality choices. Moreover, capacity building programs aiming at increasing the technical awareness among especially rural communities, creating appropriate financing incentives and instruments for investors and mass consumers with a strong engagement of local banks, and hybridizing existing diesel generators with solar PV technology in order to minimize the diesel consumption are recommended for implementation /to be implemented. Additionally, the establishment of new educational departments at universities and vocational institutes as well as research centers for renewable energy and energy efficiency in the country would create the sufficient awareness and knowhow for the sector to further develop.

1 Introduction

Numerous developing countries are finding it increasingly urgent to face growing challenges posed by energy scarcity and the consequences of climate change. This is particularly the case for vulnerable countries that are plagued with a situation of general political and economic instability—and in mid of conflict.

The Republic of Yemen (henceforth referred to as Yemen) has a rich endowment of renewables. The ongoing political and economic unrest however affects its energy sector negatively, and particularly leads to drastic electricity cutoffs across the whole country.

This crisis resulted in boosting PV market in Yemen, where PV has penetrated the market with a high growth rate, with access to PV systems reaching around 50% of households in rural areas and 75% in urban areas, translating over one billion USD private sector driven investment in PV systems for residential sector alone over the past five years, with huge untapped potential in many other sectors. This has a positive impact on the Yemeni society, not only by improving energy access during the conflict time but also by enhancing socio-economic conditions in both urban and rural areas. PV technology has reached many houses and farms, as well as some health centers and schools. This situation coupled with the dramatic reduction in PV technology prices have opened the doors for a newly emerging market with unique experiences in how the growth occurred and how the labor skills were gained and developed to serve the market needs.

1.1 Objectives

This report first describes briefly the electricity profile in Yemen. Next, it digs deeper into eight vital dynamic sectors in Yemen to estimate the technical potential, and assess PV application specifically, and energy aspects generally. Then, the report discusses the already existing financing mechanisms of PV projects, and points out to the major challenges faced. To address these challenges, three main business models are proposed. Following, the report portrays the existing supply chain of PV market in Yemen, and details more on the technical specification and cost of technologies of PV systems (PV panels, batteries, etc.) available in Yemen. Finally, several recommendations are outlined based on the acquired knowledge and obtained information.

1.2 Methodology

To accomplish this report, general and specific information about Yemen has been collected from numerous sources, including governmental reports and statistics, international reports, local and international newspapers and other media forms, interviews with local and international organization representatives and market surveys. Some unavailable data has been estimated using defined approaches based on the information collected earlier. The diagram below shows the methodology followed on this report.

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Figure 1: Report methodology

1.3 Background Information

Yemen is located at southwest of the Arabian Peninsula. According to government estimates, the total population of Yemen was around 25 million in 2013, with 70% of the population living in rural areas in around 2.5 million households, and 30% of the population living in urban cities in about 1 million households (National Information Center, n.d.).

With respect to the electricity profile, the total installed capacity in Yemen connected to the main national grid is about 1.5 gigawatt (Arab Union of Electricity, 2015). Table 1 breaks down the installed capacity by type of generation.

Table 1: Installed capacity by type of generation

Steam	Gas	Diesel	Total
495 MW	340 MW	684 MW	1519 MW

Source: (Arab Union of Electricity, 2015)

This capacity could cover merely 40% of the total population. The access to electricity in urban areas is 85%; however, this rate decreases to as low as 23% in rural areas (United Nations Development Programme, 2014). Other locations, which are not connected to the main national grid, depend either on community micro grids powered by diesel generators or on privately owned diesel generators. The map of figure 2 shows the geographical distribution of main power plants in Yemen.

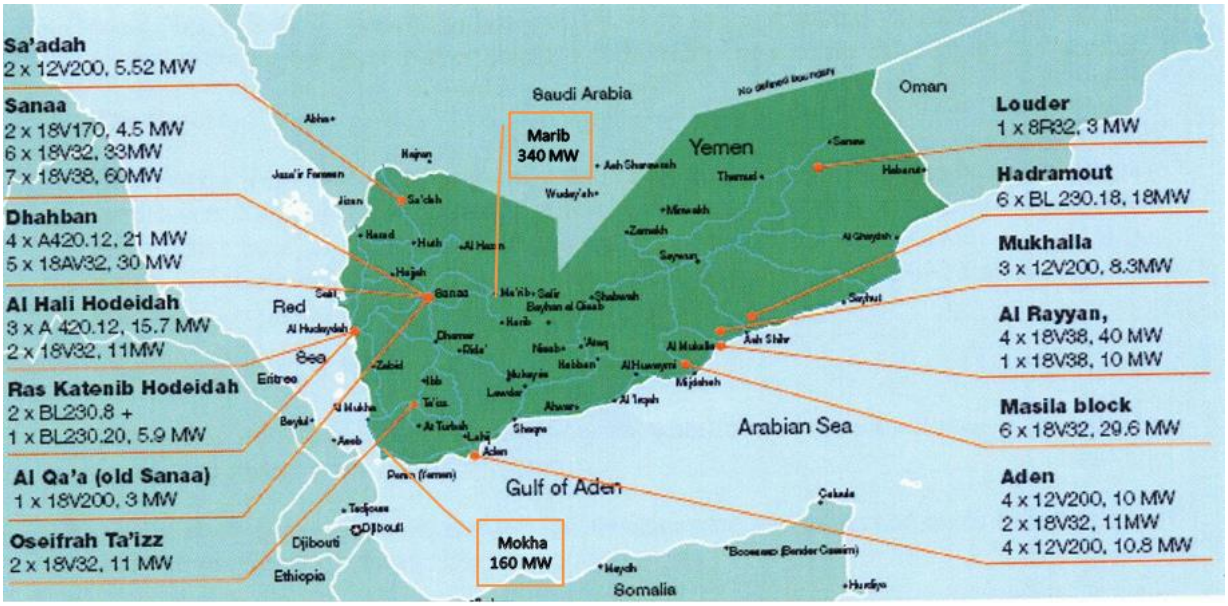

Figure 2: Location of power plants.
Source: (Ministry of Electricity and Energy, 2016)

The political conflicts in the country and the military activities have led to great difficulties, since 2011, in securing the fuel needed for operating power plants as well as in delivering the electrical energy to consumers. The fuel prices have risen up significantly becoming extremely unaffordable. The electricity generation of the power plants consequently has been considerably reduced. The subsequent situation can be described as one of electricity scarcity and power shortages occurring most of the time.

For example, the capital Sana'a, which has a demand of around 500 MW, is barely supplied by 40 MW for a few hours a day. Aden governorate also suffers from an electricity shortage; the demand of 390 MW is only covered by 190 MW at best. Other places may have no supply at all like Ibb and Al Hudaydah governorates, which both have a total demand of 280 MW. Taiz governorate, the largest governorate in terms of population, has no grid electricity supply at all to cover the demand of 111 MW (Ministry of Electricity and Energy, 2016).

The above described situation has forced citizens to resort to new alternatives. Some consumers, such as commercial shops, deal with diesel-based small independent power producers. Such a scheme is expensive and has discontinuity problems. The other alternative that is rapidly growing is the use of PV systems.

1.4 Currency Exchange Rate

The unstable situation causes currency crisis, with the exchange rate having experienced sharp fluctuations during the past year 2015 up to now. The currency rate has fluctuated from

Yemeni Riyal (YER) 214.9/USD in March 2015 to over YER 300/USD[1] in 2016. This crisis affects the prices of the services and essential commodities, which have been increased because of the volatile exchange rate and the increase of the inflation rate (Integrated Food Security Phase Classification, 2016).

Electricity tariff

Since June 2016, the Public Electricity Corporation has issued a new tariff structure in order to afford the cost of the fuel and its expenditures. Table 2 shows the old and new tariffs for each sector.

Table 2: Electricity tariff

Sector	Old tariff (YER/kWh)	New Tariff (YER /kWh)	Tariff slabs (kWh)
Residential (Urban)	6 - 9 – 12 -19	9 - 15 – 25 - 80	(0-200)(201-350)(351-700) (>700)
Residential (Rural)	9 - 19	20 - 30	(0-100)(>100)
Commercial, Industrial and Agriculture	22 - 22 - 30	80	Uniform rate

Source: (Ministry of Electricity and Energy, 2016)

[1] Official exchange rate: USD 1= 250 Yemeni Rials, Central Bank of Yemen, as of 09.08.2016

2 Sectors Assessment in Yemen

To provide a reliable foundation for this study, eight sectors have been investigated: Agriculture, Water, Health, Industrial and Commercial, Residential, Education, Street Lighting, and Public Buildings. The following subsections discuss them in more detail.

2.1 Agriculture Sector

Yemen's agriculture sector constitutes up to 14.5% of the national Gross Domestic Product (GDP), and accounts for 54% of the workforce in the country (Ministry of Agriculture, 2013). The cultivable areas distribution across the country is shown in figure 3. This shows the significance of the Agriculture for the national economy.

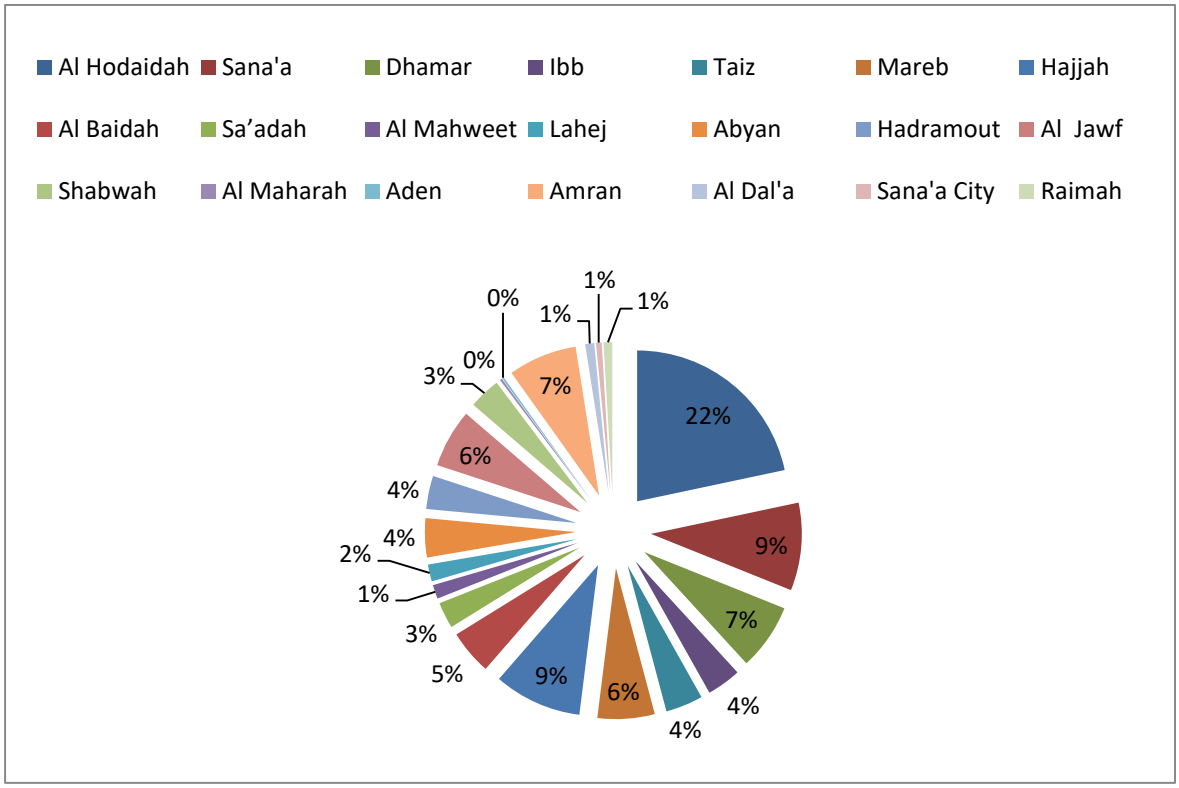

Figure 3: Cultivable areas in Yemen's governorates
Source: Ministry of Agriculture and Irrigation, 2013.

The cultivated land in Yemen depends on three main sources of water for irrigation purpose: Rain, groundwater, floods—see figure 4. In contrast to rain and floods, groundwater is highly an energy-dependent source of water that needs to be extracted and pumped. This implies that farmers face great difficulty to irrigate their crops, given the lack of diesel and its increasing price in the market.

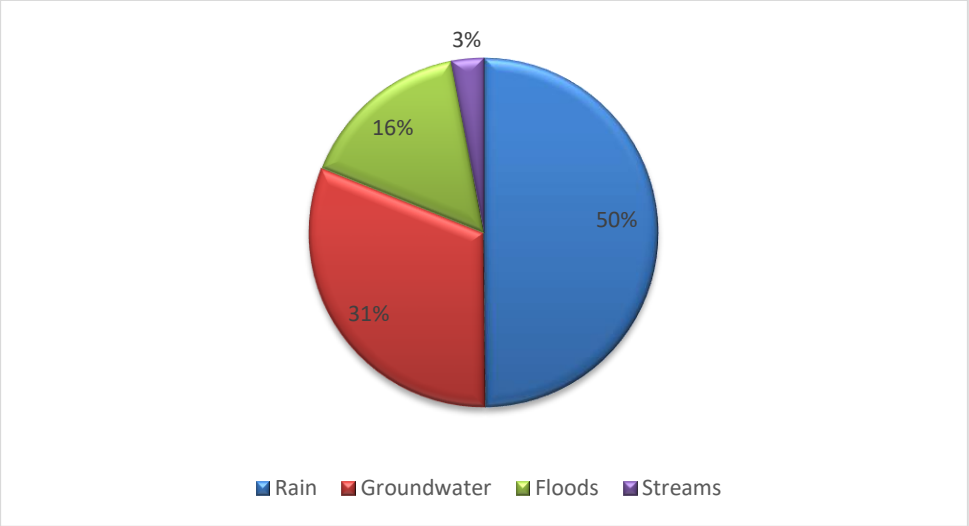

Figure 4: Sources of irrigation in Yemen
Source: Ministry of Agriculture and Irrigation, 2009

Farmers are currently not earning enough or even losing income because of the high operating expenses and the lack of demand for their crops. This is mainly attributed to the low purchasing power of people, in addition to the difficulties in the exporting process.

Moreover, the cultivation of Qat plant in Yemen is rapidly expanding, which is one of the main problems in the agriculture sector. In 2009, it was estimated that about 154 thousand hectares were planted with Qat plants, which represented about 22.3% of the total cultivated land, and consumed about 30% of water used for irrigation purposes. However, most of this consumption is in Highlands (e.g. Sana'a)—these are the areas that suffer from water scarcity the most (Ministry of Agriculture, 2013).

Current Projects

Cooperative and Agriculture Credit (CAC) Bank has the most remarkable program. They have already financed 184 solar irrigation pumps in several governorates in Yemen (CAC Bank, 2017). Food and Agriculture Organization (FAO) Yemen has also implemented 14 solar-powered water pumps with above-ground storage tanks for the vulnerable communities in 14 Districts of 5 governorates. Moreover, 110 solar pumps are under procurement process and will be installed in 2 governorates (Food and Agriculture Organization, 2017).

Opportunities

According to International Finance Corporation, there are around 100,000 diesel pumps being used for irrigation purposes (IFC, 2015). There is an enormous potential to replace diesel powered pumps that are used for irrigation purpose with solar pumps.

Barriers

- The high upfront costs of the solar irrigation pumps are still the most significant obstacles, especially for the farms that have high head wells.
- Supporting the agriculture sector with solar PV systems without restrictions on Qat farms could lead to the expansion of the cultivation of Qat plants, and hence, to an unforeseeable increase of water use.

- Most farms in Yemen use the traditional irrigation way (e.g. flood irrigation), which aggravates the already drastic water shortage problem.
- General lack of knowledge about solar PV technology and its applications
- Some farms have high head wells, especially those located in the highlands, which require more expensive and large solar PV systems, leading to longer payback periods.

Priority Areas

The agriculture sector plays a crucial role in food security and poverty alleviation in a country like Yemen. Targeting the areas with highest food insecurity rates will help the communities enhance their reliance amid the ongoing conflicts. According to FAO, 26% (around 7 million of the population) is living under the emergency levels of food insecurity across the following nine cities; Sada'a, Hajja, Al-Hodaidah, Lahej, Aldhalea, Albaidha, Abyan Shabwa and Taiz (FAO, 2016).

2.2 Water Sector

The well-being of the Yemeni Population is undermined by the lack of access to improved water sources and sanitation in both urban and rural areas. An estimated 14.5 million people require access to potable water and sanitation, including 8.2 million who are in acute need (YHNO, 2017).

Currently, those who had access to clean water (55%) find it difficult to get water as the water supply through the water grid stopped with the start of the conflict. Drilling of illegal wells, powered by diesel-based systems, is being among common ways to access water. As a result, Estimates predict the capital Sana'a to reach full water depletion within a decade at the latest, becoming the first world capital to run out of water.

Additionally, certain locations are placing exceptional pressure on scarce water sources, especially in Taiz, Al Jawf, Hajjah, and Marib governorates. For example, in Taiz, diseases such as dengue fever, diarrhea and cholera are widely spread—the number of people affected by dengue fever has reached to 17,430 in one month only (Alhayani, 2016).

Current Projects

- CARE International Yemen has executed more than 50 solar energy projects until December 2016, in areas such as Hajjah, Lahej, Amran, and Harad district of Al Hudaidah, as these are relatively poor and host large numbers of IDPs. The depth of these wells range from 30 to 80 meters and each produces around 6 cubic meters per hour. The cost of these solar systems is estimated from 5000 to 10000 US Dollar.
- CAC Bank also financed the implementation of water well projects in Wadi Amed in Hadramout, which supply the village with drinkable water and costs 50,000 US Dollar (Source: CAC Bank, written communication, 20th February).
- In Al Hudaydah governorate, the Water Emergency and Environmental Sanitation and further international organizations such as the Direct Aid of Kuwait, in collaboration with the Yemen Mobile Telecommunications, have developed 3 solar pumps.

Opportunities

General drought and thirst are one of the major challenges in the country**.** The existing drinking water projects in Yemen are operated mostly by diesel generators. Treatment plant

of Sana'a has stopped working, forcing SWWTP to re-direct the sewage outside the plant towards the agricultural areas passing by residential neighborhoods. SWWTP operates its treatment plant by two 2000 kW sets of distributed generators. A hybrid system to operate 50% of SWWTP was chosen with an estimated cost of USD 2,635,032 and a payback period of 4.7 years. UNICEF agreed to supply 50% of the fuel needed to operate the treatment plant since August 2015 (WEC, 2016).

As part of the GIZ's Water Sector Programme Yemen (WSP), the Water Basin Committee Abyan (WBC) provided water tanks, pumps and locally made clay filters to have access to basic water and sanitation (GIZ,2014).

In addition, most of LCWS water projects have stopped since the outbreak of the conflict in March 2015 because of the fuel crisis, inability to cover the operation and maintenance process and the inability of consumers to pay their water bills. Next slide shows some of these projects.

The projects execution units of the GARWSP and MWE have conducted several feasibility studies to implement water projects with solar energy, of which 27 projects are in Al Hudaydah and 5 are in Al Mahweet (Projects executive units, GARWSP 2016).

Barriers

- Poor market infrastructure, high reliance on imports and difficulty to transport given ongoing conflict. Additionally, the widespread illegal wells pose an additional challenge to accessing governmental support.
- Lack of petroleum products—particularly diesel.
- Most solar system components are still unaffordable and unreliable.
- Economy is posing a particular challenge for low and middle income groups, given the high up-front costs of the investment, high guarantee loans demanded by banks, and the derived lack of access to capital.
- Stoppage of the operational budget dedicated to water sector.
- In spite of the government showing an increasing interest to promote renewable energy technologies in this sector, there is still an enormous lack of R&D culture and dedicated professional institutions.
- General lack of standards, certifications, and codes, as well as absence of genuine skilled personnel have led to the proliferation of low-quality PV equipment.
- Lack of public awareness is still a major challenge to be overcome, which gives education a very significant role as well as the widespread poverty rates.

Priority Areas

The following areas are given particular attention with the respective reasons:

Sana'a and Sana'a City: It is home for three million inhabitants who are finding it increasingly difficult to have water access. The water supply reaches only 40% of homes in intermittent times of the week.

Taiz: It was identified as high priority area by specialists from Ministry of Water and Environment (MoWE), Local Corporation of Water and Sanitation (LCWS), Water Emergency and Environmental Sanitation (WEES) due to shortage of safe drinking water which result in the spread of dengue fever, diarrhea and cholera.

Al Hudaydah: It was identified as high priority area by specialists from MoWE, LCWS and WEES. That may be because, its residents are suffering with the onset of summer and the spread of epidemiology caused by the interruption of water supply and the lack of functional hospitals as a result of the prevailing electricity outages.

Hajjah and Sa'adah: It was identified as high priority area by specialists from MOWE, LCWS and WEES.

IDP' s Locations across the country: Access to drinking water is a major priority for IDPs. (YHNO, 2017)

2.3 Health Sector

Hospitals and other health facilities have suffered from partial or complete power blackouts during the recent periods. Several large hospitals have minimized their dependence on the national grid by installing diesel generators whose fuel demand was supplied by the government or international organizations.

Since March 2015, an estimated 21.1 million people have been affected by the ongoing conflict and need urgent humanitarian assistance (UNOCHA). An estimated 14.8 million people live without adequate health services or are affected by a high disease incidence, of which 8.8 million live in severely affected areas and urgently require aid (YHNO, 2017).

As of October 2016, only 45% of 3507 public health facilities (figure 5) that were surveyed in 16 governorates are still functional; this rate falls below 25% of facilities in several conflict-affected governorates, including Marib, Al Jawf and Al Bayda, and below 30% in Taiz, Sa'ada and Al Dhale'e. Of the remaining 55%, 274 health facilities had been damaged or destroyed in the conflict (HeRAMS, 2016 & YHNO, 2017). This is worsened by the large-scale population movements that are also driving serious health needs among Internally Displaced People (IDP), host communities and returnees.

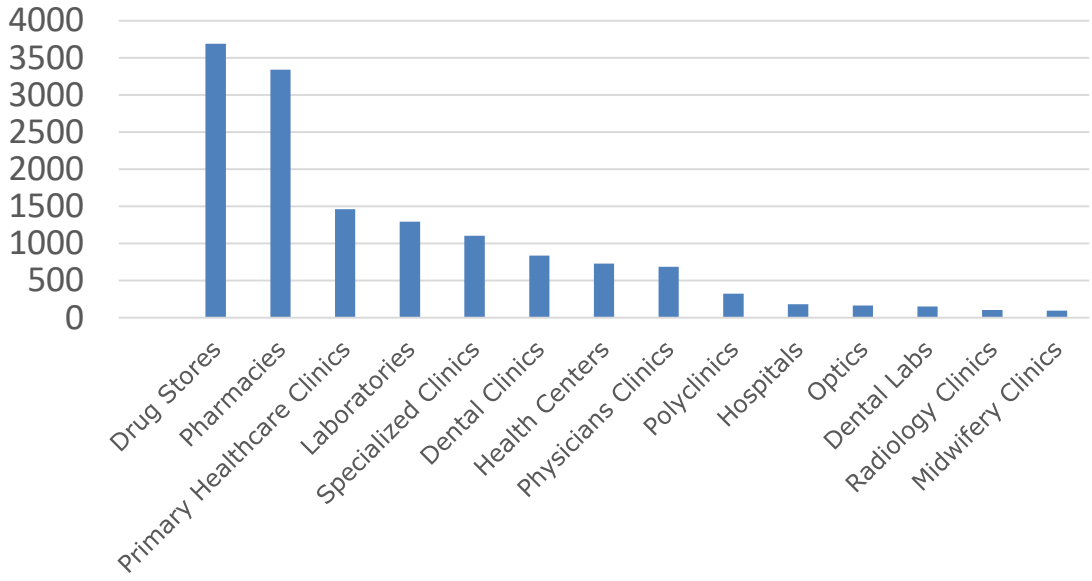

Figure 5: Private establishments distributed across governorates of Yemen (2014)
Source: Ministry of Health of Yemen, 2014

Current Projects

Several health facilities have installed solar PV systems for their necessary loads such as keeping vaccinations and medicines when low temperature storage is needed. For example, in Dhamar governorate, 13 health facilities have installed solar PV systems to ensure their required electricity supply given the frequent power cuts and scarcity of petroleum products (SABA NET, 2016). Another five health facilities in Sanhan directorate have installed solar PV systems (Al-Wahdawi, 2016)

Opportunities

The financial difficulty of Ministry of Public Health and Population (MOPHP) is to be overcome by concessional loans or grants condition on solar PV investment. This would solve the following challenges:

- Lack of electricity hinders the sterilization of medical instruments and supplies.
- Undertaken survey shows that more than half of public health facilities in the country are either closed or working at partial capacity (WHO & HeRAMS 2016).
- Lack of diesel to operate hospitals and health centers which severely affects all patients, especially those suffering severe kidney failure and in need Haemodialysis treatment (WHO news, 2017).
- The private sector across the country offers a great opportunity for investment, given their solid ability to access financing.

Barriers

- The rugged geographical nature of Yemen resulted in higher costs of solar PV system, its transportation, installation, and maintenance.
- Some health facilities' buildings are rented, making it difficult to install the solar system.

- Hospital and big health facilities have medical equipment that require enormous electrical loads (e.g. dental machines and x-rays), and catering such electrical loads from solar system is costly, besides the lack of adequate spaces for solar panels and batteries.
- Lack of expertise on large scale solar system, as well as lack of knowhow to switch from fossil-powered power system to solar energy system.
- Exclusion or lack of participation of local communities in society projects (financial and morale) which usually result in the failure of a project (e.g. rural areas Street lighting by solar energy)
- Halt of the operational budget dedicated to health services due to the economic downturn caused by the conflict.
- Politics influences the selection of projects and their locations.
- No plan from the government to electrify the health sector by solar energy, absence of coordination between local communities and central governments about the planning and financing such projects.
- No direction or desire from specialists in the upper levels of society to take the decision to buy solar energy systems instead of buying diesel generators.

Priority Areas

- According to the interview with the MOPHP, the highest priorities should be given to governorates that are having clashes, such as Taiz, Sa'adah, Al bayda, Shabwah, and Hajjah, as their health facilities suffer from completed shutdown of electricity and scarcity of diesel and financial support. useful
- Health facilities located in governorates that have become home for refugees and IDPs such as Al Hudaydah, Sana'a, Sana'a city, Ibb, Dhamar, and Amran. Then Al Mahweet, Al Dhal'a, Raymah, Abyan, and Hadramout. Al Hudaidah's residents are suffering from the onset of summer and the spread of epidemiology caused by the interruption of water supply and the lack of functional hospitals as a result of the prevailing electricity outages.

2.4 Industrial and Commercial Sector

Industry in Yemen is broadly classified into two groups: Oil and Petroleum refinery. Petroleum refining contributes to 70% of revenues and 30% of GDP. Crude oil and gas production and exports declined by 76.8% and 84.5% respectively in 2015 compared to 2014. Table 3 shows diesel consumption in the industry sector in Yemen.

Table 3: Diesel consumption in the industry sector in Yemen.

Industry	Fuel consumption (Million Liter)
Electricity power stations	1500
Private companies	241.8
Concrete industries	126.8
Other industries	73.7

Source: Ministry of Oil and Minerals (YOGC, 2012), Electricity consumption in Yemen, and Arab Union of Electricity (AUE, 2015)

Industry sector in Yemen primarily consists of micro industries (78%), small industries (19%) followed by medium to large industry (3%)—see figure 6. Micro industries are commonplace

in major governorates such as Sana'a City, Ibb and Taiz. Small industries have the highest presentence in Sana'a City compared to other major governorates.

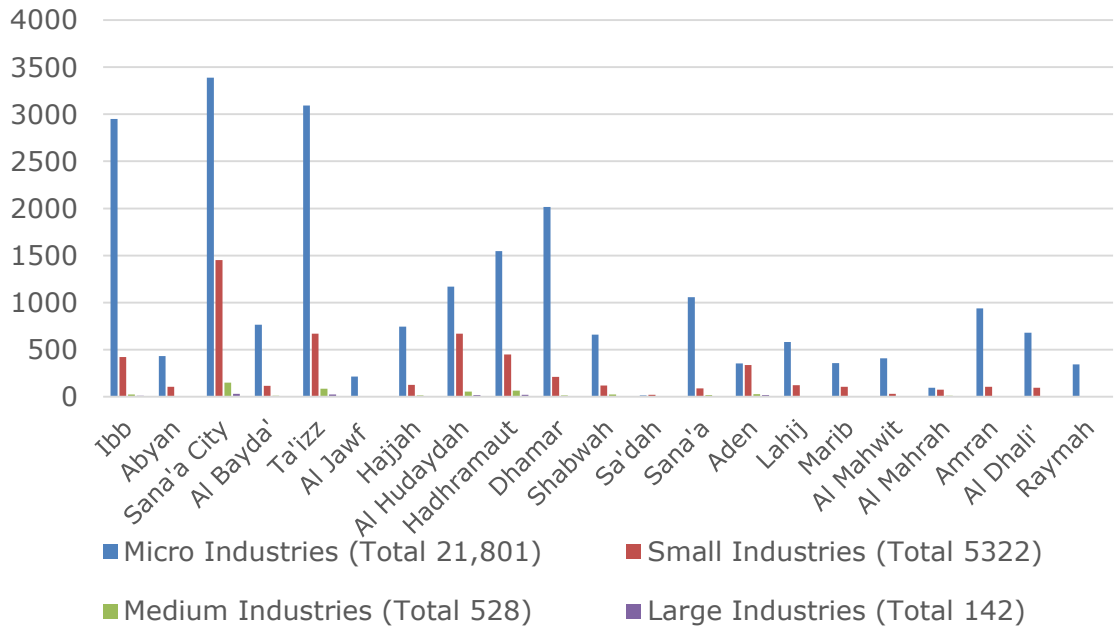

Figure 6: Industries types by size across Yemen (MoIT, 2010)

Current Projects

In 2014, the United Nations Development Program (UNDP) initiated a project aimed at the expansion of solar power technology in cooperation with The Ministry of Industry and Trade (MoIT). Due to the conflict that erupted in early 2015 and the economic turmoil that followed in the country, all activities related to promoting or funding solar technologies have been halted.

Opportunities

- Industries rely mainly on private diesel generators to meet their electricity demand.
- Diesel is becoming less and less available and is mostly only available and overpriced in the black market.
- Stores requiring diesel operated storage refrigeration systems such as pharmaceutical stores, meat vendors, dairy product vendors and grocery stores.
- Reduce reliance on diesel generators and the unpredictability of the diesel prices and market.
- Opportunities for local manufacturers to launch or expand their investment in solar PV manufacturing, assembling, installation and maintenance.
- Creating various direct and indirect work opportunities.
- Significant cut in governmental spending on energy subsidies
- Opportunity for industries to produce electricity from a green source of energy as part of their Corporate Social Responsibility (CSR).

Barriers

- High capital cost for installing solar PV systems, especially in high power consuming industries
- Unavailability of high efficiency batteries or other energy storage technologies with a long service life.
- Lack of awareness on a managerial level in industries on the benefits of solar PV.
- Absence of proper finance mechanisms and loan guarantee facilities.
- Lack of policy incentives such as Feed in Tariff or net metering.
- Unavailable trained and skilled expertise to install and maintain large scale solar PV projects.
- Generally, only medium and large sized industries can provide collaterals.

Priority Areas

Carpentry, aluminum, clothing, and metal industries were concluded to be the main sectors to be targeted for financial support as they belong mostly to the micro and small sized industries in addition to the commercial stores generally. These are the most abundant sectors in the country and have low energy consumption.

2.5 Residential Sector

The demographics of Yemen show the country is still a tribal society where 34.5% of the population live in cities, with a rate of urbanization of 4.03% between 2010-15. (CIA World Fact Book). The residential sector is of paramount importance as it accounts for around 60% of electricity consumption in Yemen. It also has great potential of energy-saving, leading to achieve the CO_2 reduction target of the country—14% reduction by 2030 (Yemen's INDC to COP21).

Current Projects

Many projects have been implemented in residential sector by individuals. Regarding the projects that implemented by the government are summarized in Table 4.

Table 4: Governmental solar PV initiatives in residential sector, most of which have been implemented by the General Authority for Rural Electricity (GARE).

	Project Name	District	Governorate	No of Houses	System Capacity Wp	Implementation Year
1	JABAL DUBA'AS	JABAL RA'AS	ALHODAIDAH	80	40	2006
2	QAWA	ALBURIQA	ADEN	75	100 - 200	2009
3	HESN BALEED	AHUAR	ABIN	40	50 - 100	2010
4	ARA'AF protectorate	ALMQATIRAH	LAHJ	100	120	2010
5	ALDHERA ALMUHAGAB -1	BANI DHABIAN	SANA'A	90	60	2012
6	MAGZAR	MAGZAR	MA'AREB	73	100	2012
7	ZAHEQ	HADIBO	SOQUTRA	92	100	2013
8	HAIF	HADIBO	SOQUTRA	40	100	2013
9	SHIZAN	HADIBO	SOQUTRA	74	100	2013
10	AFTLAMH	HADIBO	SOQUTRA	26	100	2013
11	DESHAL	HADIBO	SOQUTRA	24	100	2013
12	ALDHERA ALMUHAGAB -2	BANI DHABIAN	SANA'A	35	60	2014
13	ALGLAHEB	BANI DHABIAN	SANA'A	100	100	2014
14	ALNASHM	OTMA'AH	DHAMA'AR	65	100	2014
15	ALSAFERAH ALSUFLA	BANI DHABIAN	SANA'A	120	100	2014
16	WADI GAMILAH	OTMA'AH	DHAMA'AR	65	100	2014

Source: Ministry of Electricity and Energy (MoEE), Public Electricity Corporation

Opportunities

Enormous potential for electrification purposes in residential sector as Yemeni population is estimated to reach 60 million by 2050 (NPC, 2008), yet with a higher urbanization rate than mentioned above. Moreover, low electricity demand per household can be simply covered by a single PV panel.

Barriers

- Banks require collaterals to provide loans such as a fixed governmental salary, assets, or cash.
- Usually, price of PV systems still remains too high for a large share of the population.
- No pricing benchmark index or price controls on the side of the authorities (Corruption hinders solar energy in Yemen, 2014).
- Absence of incentive mechanisms.

- Awareness levels about renewable energy, including PV technology, still need to be improved, particularly in rural areas.

Priority Areas

- Based on climate considerations, attention should be dedicated to cities located on the coastline of the Red sea (e.g. Al Hudaydah) and Arabian Sea (e.g. Aden, Hadramout), where temperatures could reach 40 degrees Celsius in summer.
- Moreover, Sana'a should be among priority areas because it has the largest power gap (around 443MW) among other governorates (CSO, 2017).
- These cities also have dense populations— they altogether constitute more than 20% of Yemen's population (Yemen National Information Centre, 2004), and this figure could be increased due to the high growing rate of population in those cities.
- Awareness levels about PV technology is relatively more promising in these areas compared to other governorates— utilization of PV is increasingly becoming a trend in these cities (Yemen Times Newspaper).
- Additionally, these cities can attract more employees (thus increasing the market potential) as they host most industries and key sea ports in the country.

2.6 Education Sector

In the last period, Yemen's education sector has suffered from many difficulties to provide their services, and some of them have shut down. Around 17,000 schools across Yemen do not have the necessary equipment and the learning labs, especially the ones located in the villages. In the current situation, 150 schools have become shelters for IDPs and 200 schools have been turned into military barracks (SEMC, 2016). Table below illustrates the number key education facilities in each city.

Table 5: Distribution of educational institutes across Yemen[2]

Governorate	Grand Total			No. of kindergartens	No. of Vocational and Technical Institutes	No. of health institutes	Public Universities
	Public	Private	Total				
Ibb	1505	65	1,570	25	9	1	1
Abyan	461	0	461	4	5	1	
Sana'a City	310	441	751	161	13	1	
Al Baidah	570	10	580	2	2	1	1
Taiz	1472	106	1,578	128	13	1	1
Al Jawf	423	2	425	0	1	N/A	
Hajjah	1434	9	1,443	4	4	1	1
Al Hodaidah	1306	66	1,372	43	6	1	1
Hadramout	776	41	817	57	4	2	1
Dhamar	1316	12	1,328	4	4	1	1
Shabwah	567	11	578	1	1	N/A	
Sa'adah	694	1	695	0	1	1	
Sana'a	1214	18	1,232	3	1	1	1
Aden	119	65	184	51	1	2	1
Lahej	675	8	683	18	9	1	
Marib	451	4	455	0	2	1	
Al Mahweet	588	1	589	0	1	1	
Al Maherah	127	3	130	12	1	1	
Amran	1107	8	1,115	1	1	1	1
Al Dal'a	451	7	458	2	3	1	
Raimah	468	0	468	0	2	N/A	
Total	16034	878	16,912	516	84	20	10

[2] Sources: Ministry of Technical Education, 2013; High Institute for Health Science, 2013; Amein Nasher Institute for Health Sciences - Aden, 2013; Ministry of Education, 2013; Sana'a University, 2013; Supreme council for education planning, 2012; Amein Nasher Institute for Health Sciences - Aden, 2013; Ministry of Education, 2013; Sana'a University, 2013; Supreme council for education planning, 2012

Current Projects

The number of schools that use solar energy is estimated to be less than 10% of the total schools in Yemen. In the Sana'a city that contains 370 schools, UNICEF has the largest initiatives for the solar electrification of schools. The reported project is to install solar PV in 100 schools; the first phase of the project had accomplished 70 of them (Ministry of Education 2016). Table 6 summarizes the details of the system specifications.

Table 6: Solar PV system specifications for the schools

Name of the component	Battery	Solar panel	Inverters	Charge controller
No.	4	8	1	1
Capacity	150 Ah	150 W	6 kW	60 A
Total	600 Ah	1200 W	6 KW	60 A

Another solar PV system was installed in 2012 by USAID for Imam Al Shafi school in Sana'a, which powers the school's computer lab (USAID, 2012). They additionally provided a Sana'a girls' school with a solar PV system to power the school during the power cut (Yemen Times, 2012).

Opportunities

There is a huge potential for using solar PV systems in the educational buildings in Yemen, especially the buildings that are isolated from the national grid, in case there are appropriate financing and incentives programs.

Barriers

- Lack of incentives and financial mechanisms.
- Stoppage of the allocated budget for operating governmental education facilities.
- Lack of national program encouraging to power education buildings by solar PV systems.
- Absence of the sufficient knowledge to deal and maintain solar PV systems, particularly in rural areas.
- Some schools were destroyed, turned into a military barracks or inhabited by IDPs.

Priority Areas

According to the Ministry of Education, there are 2116 secondary schools which need solar PV systems as to facilitate powering 80% of these schools that have learning labs (Ministry of Education, 2017).

The universities, schools and the institutes should also be given attention to fulfil their demand of power for their labs and workshops as well as for the administration equipment—albeit the demand is relatively small particularly for schools, just to power equipment such as microphones or computer devices.

2.7 Street Lighting Sector

Yemen has been suffering from a shortage of governmental services, including necessities like security and electricity. The local community has experienced increasing street crimes, thefts, and robberies, especially in last few years.

According to the Ministry of Electricity and Energy, the Public Electricity Corporation (PEC) and the Ministry of Public Works and Highways, and based on the electricity consumption in 2010, it is estimated that 295,414 lamps were used in street lighting in Yemen. The type of technology used is high pressure sodium lamps (HPS) with the capacity of 400W and 250W. The rate of coverage of street lighting in Yemen is very limited, especially in the current situation (Ministry of Electricity and Energy, Public Electricity Corporation and Energy and Ministry of Public Works and Highways, 2010).

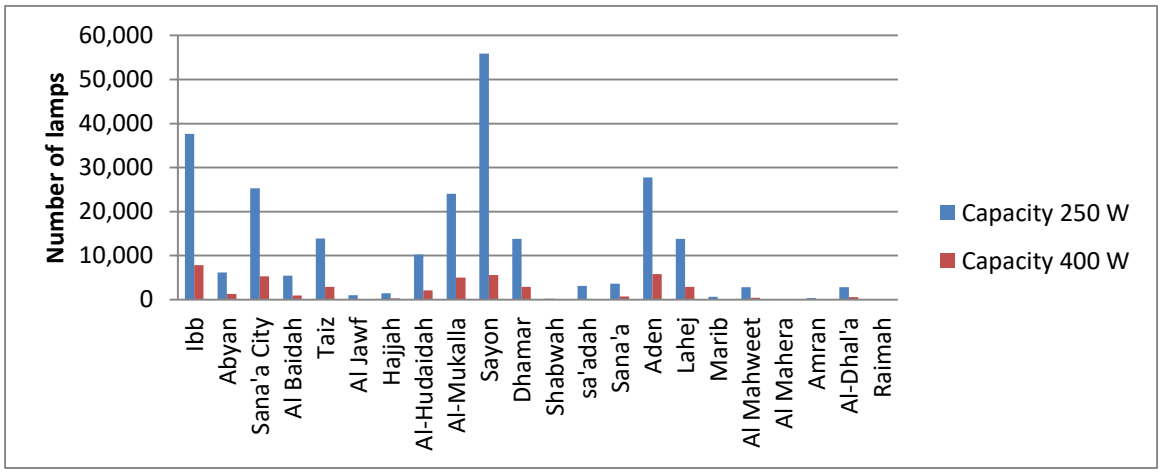

Figure 7: Estimated number of lamps in each governorate

Current Projects

There is a promotional project to illuminate parts of old Sana'a city by solar energy systems implemented by the Ministry of Electricity and Energy and funded by the CAC Bank. In 2015, an initiative called "Light it Up" was established by the community action group (CAG), supported by Saferworld, whose purpose was to install solar panels and lights in 7 areas of Taiz that had been affected by the conflict. In the meanwhile, there are other isolated initiatives which aimed at lighting the main streets in Aden (Eremnews, 2016) and Alrawdah city in Shabwah (Adenalhadath, 2017).

Opportunities

Amid the power outage and low street lighting rate, there is a significant potential to install solar led lamps in the street, especially inside cities. It is estimated that there are 18,000 km of paved streets across Yemen, 3000 km of which are located inside the cities.

Barriers

- Unavailability of reliable brands in the local market.
- High prices of materials and the costs of transportation, installation and maintenance.
- Difficulties to clean the solar panels for these systems periodically.

- Lack of adequate knowledge of such technology.
- The difficulty of protecting the systems from theft.

Priority Areas

The areas with high priority to have installed solar street lights are:

- Main streets of all Yemeni cities
- Commercial areas.
- Replacing the exiting High Pressures Sodium lamps with solar led lamps.

2.8 Public Buildings Sector

In a broad sense, the Public Buildings sector should include buildings that provide services to the public. This may include governmental buildings (e.g. ministries and its affiliated branches), libraries, mosques, parks, clubs, and so on– they should not be confused with public schools or hospitals.

In 2011, this sector accounted for around 10% of electricity consumption in the country, but the figure dropped to 8% in 2015 because of the ongoing instability (PEC, 2015). Currently, those buildings rely on either diesel generators or small-scale PV supply. Electrification of those buildings should get more attention than it used to. This will help provide services of high quality to all, and thus have positive impacts on society in many aspects– e.g. facilitating services at different ministries, promoting self-learning through public libraries, and health and fitness through clubs.

Current Projects

Table 7 summarizes the current projects that have been done in the Public Building sector.

Table 7: Solar PV projects in Public Building sector

Project	Region	Donors	Cost (USD)
Balqis lit club basketball	Sanaa	USAID	28,000
Club breeze basketball	Marib	USAID	30,000
Mina Club (lighting, fans, computers, water pumps)	Aden	USAID	109,000
Club starting soccer field	Lahij	USAID	38,000

Source: (Ministry of Industry and Trade, 2013)

Opportunities

- This sector could potentially be electrified by PV technologies, particularly through off-grid networks. The demand of this sector, estimated at 24 MW per year (PEC, 2015), can be catered by small to medium scale PV power systems.

- People involved in this sector already have some positive experience with small scale PV technologies, so that they are potentially willing to deploy this technology in large scales to meet their demand.
- In the post-conflict scenario of Yemen, the potential market in this sector may increase as it will attract and create more business—e.g. more libraries, clubs and parks to be open.
- Some of those buildings may get special attention, e.g. mosques (for a religious reason).

Barriers

- Halt of allocated operational budget for this sector as a result of the current conflict.
- Medium to large scale PV systems require high upfront capital cost, combined with lack of governmental funds. Let alone the need to construct micro-grid networks, which will incur additional costs.
- Lack of governmental motivation.
- This sector depends mainly on grants; only a few may take loans if the business can make money out of its service, e.g. monthly subscriptions.

Priority Area

Priority in Public Buildings sector might be given to buildings of governmental departments because this will motivate the government to dedicate more money on this matter.

Nevertheless, focus to buildings such as mosques, libraries and clubs would have the potential to help improve people's lifestyle, thus motivating them to invest in such facilities (in form of donations, particularly for religious reasons, or subscriptions).

2.9 Sectors Prioritization

Previous sub-sections have detailed more on eight main sectors where PV penetration is generally relevant. However, to provide a clear image on which sector would need urgent intervention, three pivotal criteria were used to prioritize afore-discussed sectors. These criteria are:

1. Urgency of Action

2. Market Potential

3. Sector Sustainability

While the first criterion mainly concerns the impact on the population due to the lack of electricity, the last two give more focus on economic aspects: Market potential is the overall number of people that are currently facing such shortage and would be directly and significantly benefitted, where a solar PV-based initiative would be undertaken; sector sustainability is based on the payment ability of the identified potential costumer/stakeholder.

With these three criteria in mind, figure 8 assesses the eight sectors against the prioritization factors. While fully and half black-shaded areas indicate high and moderate priority, respectively, non-shaded areas depict no priority. Therefore, five sectors (Health, Water, Agriculture, Residential, and Industrial and Commercial) are prioritized, and considered for further analyses on the potential market in the following sections.

Note that this assessment is developed considering further action will be taken *during conflict scenario*. This means that the assessment could change for *post conflict* scenario.

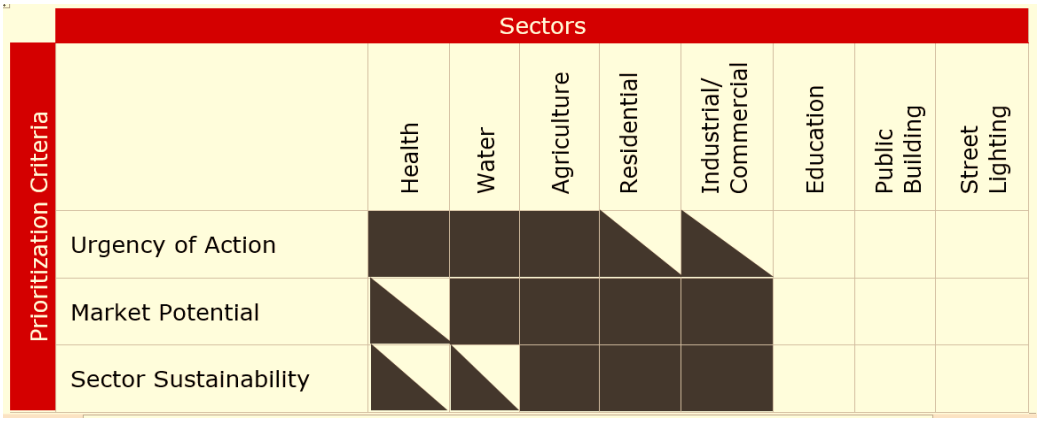

Figure 8: Prioritized sectors given selection criteria of Urgency of Action, Market Potential, and Sector Sustainability

3 The Growing and Promising PV Market of Yemen

Before proceeding to assessment of PV market in the prioritized sectors, it would be useful to shed some light on the current PV market in Yemen. The solar PV market, in a general perspective, can be classified into two main categories:

- Quality market: including companies, commercial firms and shops that are specialized in PV products. This type of market usually provides full services and entire PV systems for several applications. Many of these shops are local agencies for well-known brands and have reputable after-sale services in special workshops. The prices in this market are higher but the quality provided is better.
- Popular market: Low quality products are being sold in this market with no after-sale services. Most of the shops in this market are unspecialized and of smaller size. Prices, however, are comparatively low. This market is the source for most the systems installed especially in the domestic sector.

Stating the exact size of PV market in Yemen is certainly not an easy task given no official data is available nor is the country in a stable situation. Yet, Yemen's PV market size could be estimated starting with two pieces of reliable information (obtained through interviews): The first is that PV technology reached about 75% and 50% of population in urban and rural areas, respectively; the second is that the average typical capacity of PV system for household is approximately 150 W_p.

The estimation reveals an interesting fact that USD 1 billion[3] has already been invested from 2011 to 2016 in the residential sector alone. This figure is highly reliable and unexaggerated for two main reasons. The first is that estimation considers only average values (for instance, 150 W_p is the average capacity; there could be people who installed much higher capacity). The second is existence of other sources stating that the PV market in Yemen is over USD 1 billion. For example, the Studies and Economic Media Centre, Sana'a, reported that actually the PV market has exceeded USD 2 billion only for a 2-year period from 2014 to 2016 (Alwly, 2016).

3.1 Potential Market in The Prioritized Sectors

The following sub-sections explain in detail the potential of PV market in the five prioritized sectors.

3.1.1 Health Sector

The health sector is of top priority provided:

1. The extent of the population uncovered by basic health services (urgency of action).

[3] It is estimated that 75% of the urban households (750,000 households) and 50% of the rural households (1,250,000 households) are using solar PV systems with the average capacity of 150 W_p, including 1kW inverter, 10 A charge controller and 100 Ah battery. The average cost of this solar system is around $400, which provides an overall cost for 2,000,000 systems at (a) $800,000,000. It is moreover estimated that 50% of the systems' batteries have been replaced, with an average cost of $150 per battery, which means that the total invested costs amount to (b) $150,000,000. Additionally, the installation costs, including wiring and switches, amount to (c) $50,000,000. Overall, (a)+(b)+(c) provide a sum of 1 billion USD.

2. The extension of the health sector: 4170 *public health facilities (of which 243 hospitals)*, around 181 *private hospitals*, and 14100 private health establishments (including, drug stores, pharmacies, primary health care clinics, health centers, radiology clinics, etc.) (Ministry of Health of Yemen, 2014[4]) (*market potential*).
3. The booming private health hospital is being highly developed (*sector sustainability*).

Estimate shows that up to 14.8 million people live without sufficient health coverage, more than a half of which requires urgent aid (YHNO,2017). This is a consequence of the financial crisis the Ministry of Public Health and Population (MOPHP) has been undergoing.

Currently, only 45% of public health facilities are still functional in 16 out of the 22 governorates (HeRAMS, 2016). The Public Health of Population Office is interested in installing solar PV systems in specific health facilities in several provinces.

3.1.2 Water Sector

The water sector has been identified as of top priority, because water overlaps with Health, Agriculture, and Households. Around 45% of the total population is unserved with basic water needs (WHO, 2015) (*urgency of action*). A large share of the population living in urban areas have seen a reduction or complete stop in the water they receive through the public network. Underlying causes are: Pipe network leakages, inability of consumers to pay their bills, and conflict-related impacts.

Additionally, poor performance of sewage systems presents a major challenge in densely populated areas. There are 180,000 wells powered by diesel generators across Yemen (IFC, 2015[5]) for drinking purposes and 554 water pumps connected to the grid across urban areas (Ministry of Electricity and Energy, 2015) (*market potential*).

The Internal Collateral Fund and Aggregator Principle Business models, explained later, aim to provide a sustainable solution to the potential of this sector (*sector sustainability*).

3.1.3 Agriculture Sector

The agriculture sector, a key sector to poverty reduction, has been identified as of high priority due to its role on: 1) Food provision, and 2) Employment (and therefore empowerment). The sector currently allocates half of the national workforce. According to a 2007 IFC report[6], 77% of Yemeni enterprises were farms (1,400,000 out of 1,810,000), although more updated figures state around 1,900,000 farms (Ministry of Agriculture, 2013). There are 100,000 diesel-powered irrigation pumps in Yemen (IFC, 2015[7]), although a vast majority of which are owned by small farmers with more difficult access to finance (*market potential*).

Technically speaking, around 93% of the extracted groundwater is used for agriculture purposes, which implies a high widespread use of water pumps. Economic saving potential of

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[4] http://www.moh.gov.ye/arabic/docs/Report2014.pdf

[5] http://www.fao.org/nr/water/docs/SPIS/10_Colback.pdf

[6] http://yemennetwork.org/en/wp-content/uploads/2015/02/credit_loan_guarantee_feasibility_presentation_english.pdf

[7] http://www.fao.org/nr/water/docs/SPIS/10_Colback.pdf

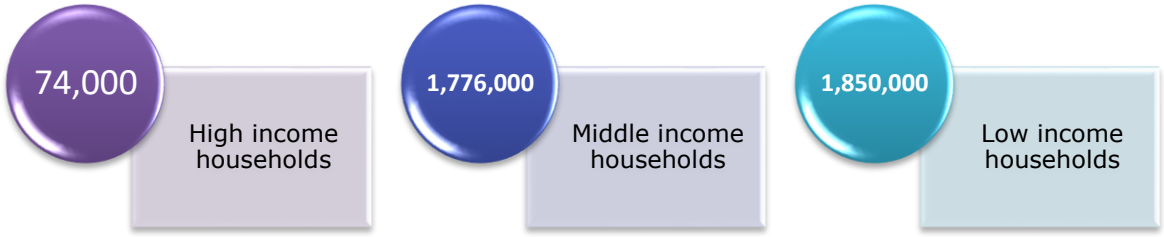
solar PV technology because of the increasing price of diesel in Yemen, which indicates a challenge to the farmers in crops irrigation (*urgency of action*). FAO has already penetrated the agriculture sector by installing solar pumps, thus facilitating the process of finding reliable partnerships. There are at least 1000 big farms across the country connected to the grid, with potential ability to pay (Ministry of Electricity and Energy, 2015) (*sector sustainability*).

The Internal Collateral Fund and Aggregator Principle Business models, explained later, aim to provide a sustainable solution for the small farms (*sector sustainability*).

3.1.4 Residential Sector

The residential sector was identified as of relevant priority relying on the fact that around 60% of distributed electricity output is consumed by households (Ministry of Electricity and Energy, 2015).

According to United Nations estimates, population in Yemen as of 2017 reached 28 million[8] Taking in consideration there is an average of 7.4 people per household, there are approximately 3.5 million households in Yemen, of which 2% are high income households, 48% middle income and 50% low income households[9]. The market potential is therefore:



People rely on alternative energy sources such as gas, wood, kerosene (*urgency of action*). Priority areas in this regard are densely populated regions of the country. The Yemeni government has throughout the last years undertaken several initiatives to empower the residential sector. The 74,000 high income households fulfill the sector *sustainability criteria*. The remaining households are candidates to be supported by the developed business models: My Solar PV, the Internal Collateral Fund, and the Aggregator Principle.

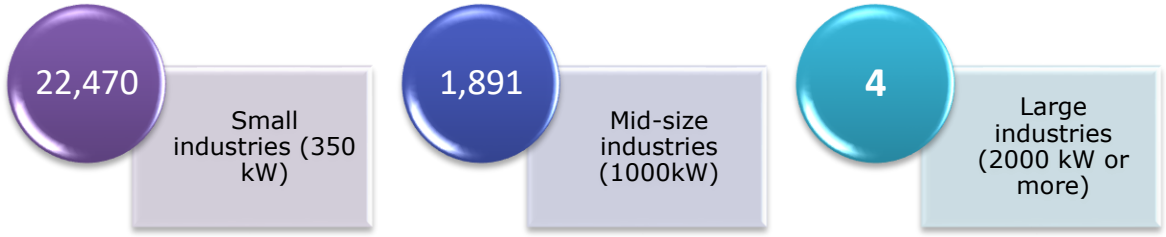
[8] http://www.worldometers.info/world-population/yemen-population/

[9] http://www.yementimes.com/en/1570/news/812/Two-percent-of-Yemenis-controls-Yemen%E2%80%99s-wealth.htm

3.1.5 Industrial and Commercial Sector

The industrial and commercial sectors have been the identified as of relevant priority for the following reasons: Petroleum refining constitutes of 70% of national revenues, and employment (therefore empowerment). Industries and stores rely mainly on private diesel generators to meet their electricity demand (*urgency of action*).

The market potential of the sector has been roughly estimated using the Ministry of Electricity and Energy's utility billing data for 2015. Given lack of data for the off-grid industries and stores, the below numbers are significantly underestimated:



Especially the large size industries would benefit from a high ability to pay (*high sector sustainability*). The remaining industries are candidates to be supported by the developed business models described later, the Internal Collateral Fund and the Aggregator Principle.

3.2 Summary of Market Potential

To summarize, Table 8 below has been developed to illustrate key market potential in Yemen in terms of *market size* and *estimated funding needed*. The analysis shows that while the highest technical potential is those of middle-income households (at around USD 23 billions) and small farms (at USD 16 billions), the lowest is that of water pumps combined at around USD 0.10 billion.

Table 8: Estimated market potential of each sector given current annual cost of diesel consumption and cost on investments on PV systems.

Potential Beneficiaries	Suggested PV panel installed power (kWp installed) (based on 5.5 peak sunshine hours/day) for 100% solar	Solar Energy Fraction (%)	Total cost/client (USD)	Market size* (No. potential clients)	Estimated funding needed/client type (based on conservative estimates of solar share) (million USD)
Private Hospital (90kW)	393	40	84,829	181	15
Small farm (17kW)	109	100	162,000	100,000	16,200
Big Farm (34kW)	218	100	324,000	122	40
High income Household (5kW)	13	100	38,182	74,000	2,825
Middle income household (3kW)	4	100	13,091	1,776,000	23,249
Low Income household (1kW)	1	100	4,364	1,850,000	8,073
Rural Household (0,3kW)	0	100	818	63,021	52
Small industry (350kW)	509	40	274,909	22,470	6,177
Mid industry (1000kW)	1,455	40	785,455	1,891	1,485
Large industry (2000kW)	2,909	30	1,178,182	4	5
Water pump for domestic use (1kW)	7,593	30	589	180,000	106
Total	N.A.			**4,067,689**	**58,227**

Notes on Table 8:

- To provide a reliable foundation for market potential assessment, the potential beneficiaries considered on this table are only those that are highly relevant to private rather than public businesses. This means there are a lot of other beneficiaries excluded because they are more interested in grants than loans, particularly public-owned business/projects, and NGOs.
- Estimations of the typical capacity of business-as-usual approach (column 1) have all been developed for off-grid stakeholders (that is, powered solely by diesel generators without reliance on electricity from the grid). In practice, this estimation is still valid even for on-grid costumers as well, given the increasing unreliability of the national grid.

- While the second column represents the suggested capacity of PV Panels (in kWp) to hybridize or replace the existing business-as-usual systems (i.e. diesel generators), the third column states the recommended share of PV power penetration in percentage.
- The presented costs of a 1kWp PV system (column 4) include panel, inverter, controller, batteries (if necessary, e.g. households) required wires, system installation costs, and O&M included in PV supplier contract. The current prices of these components have been obtained from direct interviews with relevant PV suppliers, and lead to a price range of USD2800-3000kWp (for the earlier described systems).
- The market size data (column 5) has been obtained mainly from the Ministry of Electricity (2015). This data is however for on-grid stakeholders, meaning that the market potential numbers are underestimated. However, no reliable data was found for off-grid stakeholders.
- The market size data for the water pumps for irrigation purposes and domestic use have been based on the IFC, 2015 report[10].

[10] http://www.fao.org/land-water/en/

4 Financing Mechanisms of PV Projects: Challenges and solutions

4.1 The Current Financing Mechanisms

The common way to finance solar PV systems in Yemen is through private savings in the form of cash payments. Until now no presence of any specific business models for selling solar PV systems exists, such as the pay-as-you-go model, which allows people to pay for their systems through mobile money and without any high upfront costs. Furthermore, there are several financial institutions and banks that provide financing facilities for costumers. The leading financial institutions engaged in the PV business are listed below:

- Small Enterprise Development Fund (SEDF)
- Yemen Reconstruction and Development Bank- Islamic Branches
- Cooperative and Agricultural Credit Bank-CAC Bank
- Tadhamon International Islamic Bank
- Islamic Finance – CAC Bank
- Yemen International Bank
- Yemen Commercial Bank
- Al-Amal Microfinance Bank
- National Microfinance Foundation
- Alkurami Islamic Microfinance
- Azal Microfinance

The following paragraphs explain key initiatives of major banks/financial institutions in the PV market:

- Small Enterprise Development Fund (SEDF) has 7 main branches in Yemen located in Sana'a, Ibb, Dhamar, Taiz, Aden, Al Hudaydah and Al Mukalla. The activities of SEDF cover 14 governorates (Small Enterprise Development Fund , 2016). Three types of PV systems could be financed by the SEDF, as follows:
  - Residential and commercial shops' systems: SEDF has been financing over 500 systems, the maximum loan amounts are YER 1,000,000 ($4,000)[11] for a payment period of 1.5 to 2 years with an interest rate of 13%.
  - Solar irrigation systems: The maximum loan amount is YER 10 Million ($40,000) with a payment period of 3 years and an interest rate of 11%.
  - PV systems for small enterprises and workshops: Small Enterprise Development Fund (SEDF) is also financing the SMEs and industrial workshops; the maximum loan amount is YER 10 Million ($40,000).

- The Yemen Reconstruction and Development Bank (Islamic Branch) has started financing solar PV systems since 2015. The beneficiaries of the loans are approximately 700 persons. Around 20% of these loans have been granted to commercial shops while 80% have been provided to residential households. The interest rate is 4% if the loan is repaid

[11] Exchange rate: USD 1 = YER 250

over a period of 6 months, and 11% if the loan is repaid over a period of 12 months (Yemen Reconstruction and Development Bank , 2016).

- CAC bank has financed over 300 solar irrigation systems: the first 172 systems got grants with an interest from 5% to 20%, according to the payment period. The beneficiaries got a 20% investment grant if they paid in cash, 15% if the loan was repaid over a period of 1 year, 10% grant if the loan was repaid over a period of 2 years and 5% grant if the loan was repaid over a period of 3 years (Cooperative & Agricultural Credit Bank , 2016). CAC Bank also has started financing PV systems for residential applications: around 1,000 PV systems so far, the interest rate of which is 11% with a payment period of 1 year.

- Al-Amal Microfinance Bank started in 2015 financing solar PV system applications. The bank targets the following sectors:
    - Micro and small entrepreneurs, males and females.
    - Individuals with income-generating activities and those offering transportation services.
    - Salaried individuals with business projects.

  The number of beneficiaries reached 2,235, with loans' ceilings between YER 30,000–1,000,000, and the payment period is between 6 to 24 months (Al-Amal Microfinance Bank, 2016).

- One of the governmental bodies facilitating purchasing of PV systems is the General Authority for Post and Postal Savings, which has 356 branches. One of its services is delivering salaries to around 520,000 governmental employees, and dealing with more than 60 suppliers selling their products by installments. These products include PV systems, wherein the role of the General Authority for Post and Postal Savings collects the monthly installments and receives a 3% commission for this service (General Authority for Post and Postal Savings, 2016). It is worth to mention that some of these suppliers who deal with the General Authority for Post and Postal Savings could not receive their monthly payments as a result of the recent situation of instability and the deferment of governmental employees' salaries. The reason behind this fact is that these public facilities are no longer able to offer their services and consequently there is a lack of generated revenues, which are needed to pay salaries for employees.

4.1.1 Local Donations for Solar PV Systems

Local donations in the electricity sector are limited to small-scale and in some cases individual initiatives from some businessmen, charities, or foundations. The data about these activities are scarce making it difficult to know most of the initiatives taking place throughout Yemen. One of the well-known initiatives called "Yemen Our Home" is a campaign supported by UNDP aiming to collect donations from Yemenis inside and outside the country. The resources are then implemented to support vulnerable communities by installing solar PV systems to power some essential services such as hospitals, clinics, drinking water, farmers, etc.[12] For instance, Besat Al-Khair Foundation for Charitable and Development took initiative to distribute solar

[12] More details available at, http://www.yemenourhome.org/en/campaigns/show/8

PV systems for poor people. The foundation has already distributed 10 solar PV systems, each system consists of 100W solar panels, 70Ah batteries and 5DC lamp.

4.2 Required Conditions and Eligibility

The banks that provide loans for the customers to buy solar PV systems require the following conditions and procedures:

- Gold, commercial guarantee or cash deposit has to be provided by non-employed clients as a guarantee.
- For employees, agreement between the bank and the employer should be reached.
- The salaries of employees should be received through the financing bank.
- Price quotation has to be provided.
- The application has to be supported by persons' guarantees[13] in the case of governmental employees.
- The monthly installment should not exceed 50% of the salary.

The current financing mechanisms for PV system do create some barriers for accessing loans. The aforementioned conditions require beneficiaries to provide guarantees which are considered unattainable for a majority of people preventing the regular Yemeni citizens to have access to credit. On the other side, those receiving finance do fulfill these strict requirements, which lead to a low default on the payments rate.

Another constrain is the lack of technical support and knowledge within the financial institutions about the risks and technology based feasibility. There is a need to involve international financial institutions with the local banks to facilitate financing solar PV systems by soft loans. At the consumer's side, in some cases religious barriers could prevent conservatives from applying for interest based loans. Some solutions with Islamic banking can be explored to target such conservative consumers.

4.3 Proposed Financing Business Models

The assessment of financial aspects pertaining to solar PV projects reveals the major obstacle is not the lack of funds as much as it is the guarantee provision that borrowers should provide. The following financing business models are therefore developed to mobilize the already existing financial potential through solving the problem of lack of borrower guarantees and strongly engaging local actors through building a new relationship between the technical and financial service providers and the service users in different sectors.

All developed business models rely on at least one or more of the following three components, where a combination of two of them often prevails.

4.3.1 Internal Collateral Fund (ICF)

The core idea of ICF is to provide financial support by International Financial Institutions (IFIs) in form of a ***credit line*** to local financial partners (banks, MFIs) to be used exclusively for the establishment of an ICF to guarantee only Solar PV investments' loans.

[13] Two to three governmental employees have to guarantee the loan in case of repayment difficulties.

For every loan the local bank/MFI provides, the ICF will cover 50% (in specific cases could be higher) of the guarantee cost as an insurance service in case of bankruptcy of the client making investment on solar PV. For every "**partial guarantee request**", the client (borrower) transfers a fee (adapted to the assessed project risk) to the ICF for the part of the guarantee that the client himself cannot provide.

The local bank/MFI is aware that by the end of the period (say, 5-10 years) it will have to return the used fund to IFIs at least with no losses (corrected by inflation rate). This implies that the *overall collected fees by the ICF paid by borrowers should exceed the disbursed amount by the IFI's credit line to the local bank/MFI to cover the losses of defaulted loans*. This incentivizes the adequate management of the fund, thus avoiding conflict of interests by ICF's internal management.

In this model, risk-sharing principle fundamentally applies. That is, the risk is shared between the borrower, the local bank/MFI (to the extent that it has to return the used credit line amount to the IFI), and the ICF (funded by the IFI). The need of a guarantee by the borrower does not fully disappear, but its amount decreases significantly, providing new access to finance to a wider range of clients, which until now remained underserved. Such a model can be applied across all analyzed and vital sectors (health, water, agriculture, etc.).

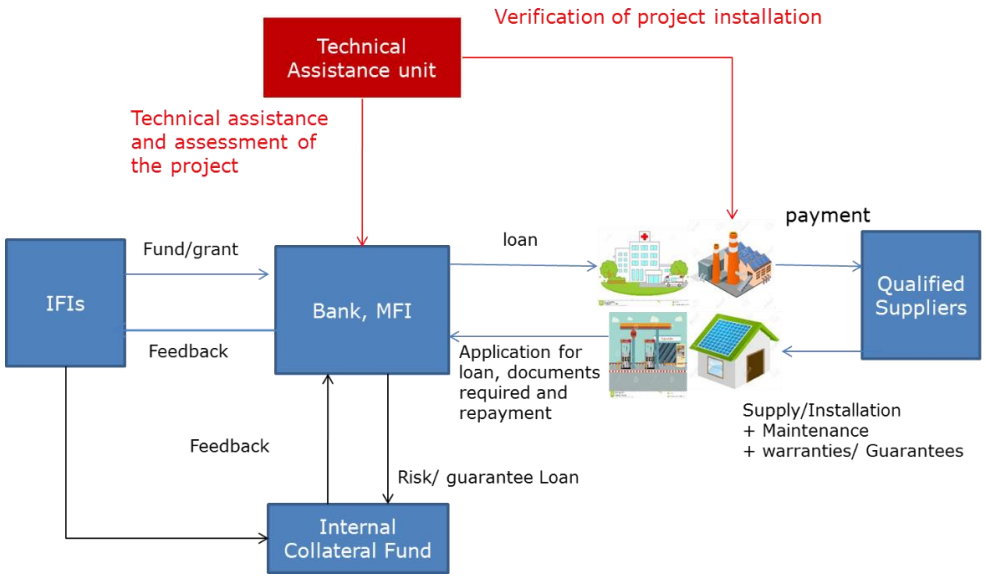


Figure 9: Block diagram of Internal Collateral Fund (ICF) business model

4.3.2 Aggregator Principle

This model aims at providing financial support to (bigger) entities/clients aiming to take the loan to benefit a wider range of users, whether they are PV suppliers (ready to act as ESCOs), energy cooperatives, community service organizations, etc. The borrower ensures the necessary mechanisms to receive the monthly installments from the end users (the use of mobile money would be a convenient means to reduce transaction costs).

This model would ensure the following advantages**:**

- Benefitting from derived economies of scale and reduction of transaction costs (one single client with a bigger impact)
- Clients (aggregators) are closer to the end community and act as intermediary for users in remote areas, often with lack of financial and technical knowledge.
- A group of small users "teaming up" can collect larger guarantees and therefore access finance, which is not possible if borrowed "alone".
- It can be applied across almost all analyzed sectors and achieve larger impact.

However, entities must fulfill certain eligibility criteria to act as "Aggregator", for example:

- Strategic position in the market (accepted by public and private actors, decision making power, ability to mobilize community, or accepted service provider (of any type of service).
- Solid financial capacity and guarantee provision.
- Effective installment collection system (e.g. Mobile money service (strongly preferred but not a must) with mobile network availability)
- Solar PV experience is preferred but not a must.

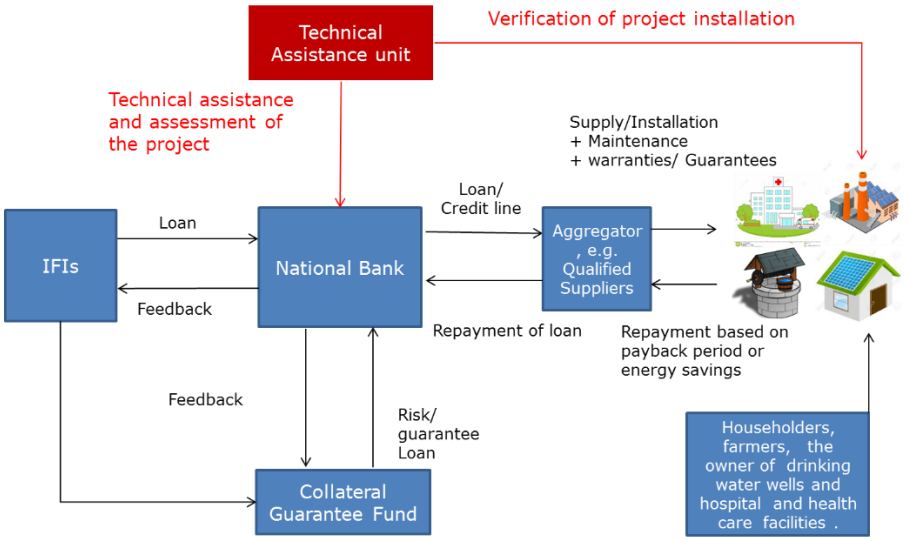


Figure 10: Block diagram of Aggregator Principle business model

4.3.3 My Solar PV

The core idea of My Solar PV model relies on loaning the Solar PV system directly instead of the capital needed to buy the system. The bank buys the system and rents it to the client in installments. The full property is then transferred to the client when the paid rents balance out the initial cost borne by the bank plus an ex-ante agreed amount (the required guarantees by the bank follow the same conventional rules). Depending on the financial capacity of the client, the model can be applied to a full upfront acquisition by the bank (known as Al-

Murabaha finance) or to a share of the system, the client thus paying the remaining part upfront (Musharakah finance).

The following are some advantages gained from this model: it is coherent with Islamic finance principles, where interest-based loans are not allowed and discouraged among potential borrowers. It is particularly of relevance in sectors where the Aggregator Principle is not applicable (single households, for example). Small farms could additionally be a potential beneficiary.

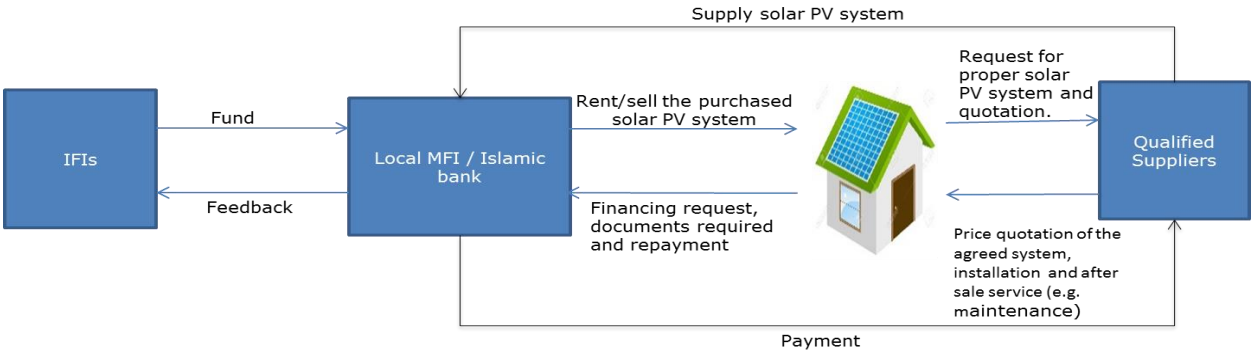


Figure 11: Block diagram of My Solar PV business model

4.4 Business Models Sustainability per Sectors

The sustainability of the developed business models is further investigated for all prioritized sectors in such a way to create a portfolio where the profitability of the Self-sustainable business model balances out the higher risk derived from investments in the Development Support business models. Figure 12 maps out the sustainability of each business model over the prioritized sectors.

	Prioritized Sectors												
	Health		Water	Agriculture (Farms)		Residential					Commercial / Industrial		
Business Models	Private	Public	Non-farm wells (e.g. urban)	S - 17 kW	L - 34 kW	Rural - 0.3kW	S - 1 kW	M - 3 kW	L - 5 kW	Villas - 10 kW	S - <= 350 kW	M - up to 1000 kW	L - >= 2000 kW
IFC													
AP													
My Solar PV													

Self-sustainable Business Models/ Mainstream | Partial development support/Moderate | Development Support Business Models/Vulnerable | Not Applicable

Abbreviations:
ICF: Internal Collateral Fund
AP: Aggregator Principle
S: Small
M: Medium
L: Large

Figure 12: Sustainability of business model for prioritized sectors

5 Supply Chain

5.1 Components Supply

Most of the key solar PV system components are imported from Asian manufacturers, and minor imports come from other countries, such as Germany and USA. Chinese products dominate the PV market in Yemen.

Some deals are arranged in Dubai, where local importers purchase solar-related products—manufacturers commonly have a representative office in Dubai. Additionally, and as a result of the importation constraints through the seaports that require ships to go to Djibouti for inspection processes, delivery time is increased up to 40 days. For this reason, some importers currently prefer shipping their goods to UAE and then reach Yemen through land transportation.

The importation process is conducted either by direct communication between manufacturers and local importers or through dedicated commercial offices (managed mainly by Yemenis) located in the exporting countries, particularly China. The role of these offices is to assist importers to arrange deals and ship the goods to Yemen.

Recently, due to the foreign currency shortage and increasing transportation costs, many investors switched their business from importing to retailing. The diagram of figure 13 below illustrates the supply chain process.

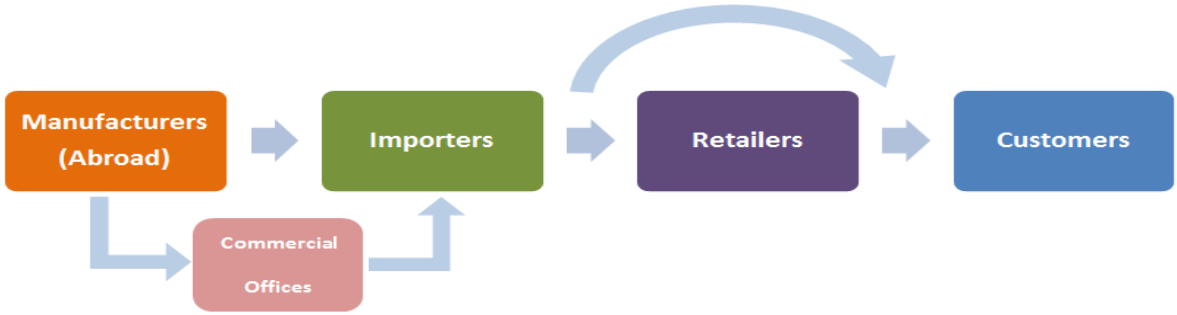


Figure 13: Supply chain process

The type of business differs between companies; some of them are corporates or limited companies, others are agencies or individual business proprietors. Individual business proprietors have large penetration rates in the current market. Annex 1 provides a list of the main companies that are working in the solar PV technology in Yemen. Lately, due to the great and guaranteed profits, many companies expanded their business by launching additional sectors/branches for renewable energy products.

The PV technology attracts various small shops: computers, mobile, electrical and electronics, building material, and other unspecialized shops. The specialized firms in the solar energy field have low shares in the market. The prosperity in the solar PV market is a result of the efforts of private sectors who invest their own money without enough financial incentives. These companies are usually of medium size according to the Ministry of Industry and Trade.

The shipment of components from the manufacturer to Yemen could take several paths. It can be directly imported through the sea to one of the seaports in Yemen (Aden, Al Hudaydah, Al-Mukalla); in other cases, companies import the products through the sea to Oman or Dubai

and then to Yemen by land crossing the boarders. Few quantities are imported through airports.

Figure 14: Shops selling PV systems in the Yemeni capital, Sana'a
Source: RCREEE

As for prospect of expanding solar PV companies: The companies running the PV business have a promising prospect to expand their businesses in the following fields:

- PV assembly workshops, as this business could increase company's profit.
- Maintenance branches, which can add a new type of business that is in need by the PV system owners. This business has already been started by some centers.
- Establishing PV training specialized centers in order to educate and qualify skilled technicians.
- Retail shops may focus more on the rural areas as the market there has a strong potential.

5.2 Technical Product Specifications

Due to the large market growth, a wide range of products are imported to Yemen. This variety includes all components of a PV system, from PV panels, inverters, batteries, charge controllers to wiring and all other accessories.

For solar panels, both crystalline silicon technologies, mono-crystalline and poly-crystalline types are available in large quantities, whereas the availability of thin film technologies is significantly limited. Well-known high quality brands such as Yingli and MITSUBISHI are available in the market with lower demand than many other cheaper brands. This situation is reflected on the quality issues expressed by many users. The manufacturers provide panels nameplates with Standard Testing Condition (STC) parameters (P_{max}, V_{mp}, V_{oc}, I_{mp}, and I_{sc}). The compliance of the actual parameters with the nameplate parameters is subject to the panel quality. Low quality panels have shown deficiencies from the label data out of the acceptable range. Common modules often claim conforming international standards and certifications such as CE and ISO 9001 while the high quality solar panel brands show additional standards and certificates such as IEC 61730, IEC 61215, ISO 14001 and TUV. The suppliers who are listed on Annex 1 are considered among the qualified suppliers who offer high quality solar systems in Yemen.

For small residential loads, 150W solar panels are typically used, while 250W solar panels are commonly used for large residential loads. 300W solar panels are widely used in solar irrigation pumps. The fabrication of solar panels' structures has been well developed during the last couple of years where many local workshops are being specialized in this field.

As for charge controllers, Pulse Width Modulation (PWM) devices are widely available since the early days of market expansion, while Maximum Power Point Tracking (MPPT) devices, which are considered to be a better technology, have recently started taking some share in the market. The MPPT prices are still high for average consumers. Integrated MPPT with inverters are also available but still highly priced. Most PWM and MPPT are available with 12V and 5V output ports for DC loads; common charge controllers are provided with a LCD display. It is estimated that 60% of the solar PV systems installed have charge controllers, and their absence is one of the main causes behind battery failures.

With regard to batteries, deep-cycle technologies, especially Absorbent Glass Mat (AGM) and Gel technologies, are commonly used. These technologies have around 1000 cycles at 50% Depth of Discharge (DoD). Batteries with capacity of 50Ah, 70Ah and 100Ah are commonly observed in small and medium households, and small shop applications, while 200Ah batteries are frequently used in large household applications.

Due to lack of technical awareness and low prices of car batteries, a large number of consumers use car batteries for PV applications; this practice has a strong effect on the system performance and lifetime. With the growth of customer maturity regarding technical awareness, people have switched to deep cycle batteries in some cases if it is affordable. The lifetime of batteries differs from one type to another however, the common batteries that exist in Yemen have a lifetime ranging from 1 to 3 years. It is worth mentioning that cost of battery is usually the highest in PV systems, accounting for 28% to 43% of the total AC system cost (including an inverter). Further details on battery cost can be found in Table 7.

Pure sinewave and modified inverters are available in the local market. Inverters integrated with MPPT charge controller have increasingly become popular yet at higher prices. Inverters with rated power lower than 1000W are used in small households while large ones use inverters with capacity higher than 1500W to insure supplying high loads such as refrigerators, washing machines and water pumps[14]. Table 9 below lists some brands of solar PV components in Yemen.

To power essential applications such as internet modem, TV, LED lamps and phone chargers, consumers usually install 12V DC wiring to avoid inverter losses and costs.

Table 9: Some of the most common existing brands in Yemen

PV Panels	Battery	Charge Controller	Inverter
LG Multix	GARMAN	GARMAN	GARMAN
RAGGIE	RAGGIE	RAGGIE	RAGGIE
OREX	BLT	BLT	BLT
SMART POWER	SMART POWER	SMART POWER	CNBOU
NORNK	BESN	BESN	ZYY
LG MonoX	Narada	SOLAR POWER	YOYO
ZOCEN	MUST	MUST	MUST
Alpha	Long		C&M
Copex	Copex		CIEMANS
SANDISOLAR	LUMINOUS		LUMINOUS
SUNPOWER	Trojan		ARTronic
CROWN	New Max		Light Wave
GROWING	D&D		MICROTEK
MITSUBISHI	SU-Kam		Su-Kam
PTL SOLAR	OLITER		
DOKIO	LCB		
SACRED SUN	SOLAGURD		
AE Solar	Rocket		
ENERGY SOLAR	TOP GEL		
ROXON	ROXON		
TATA	SUN CYCLE		
LG	SOLAVOLTA		
Solar tech AxSun	LUXURY		
solar	ENERSYS		
Yingli	TBE		
Trina Solar	ICS		
	Metro PSS		
	Sacred Sun		
	SOLITE		

[14] Small water pumps are used to lift the water from the ground storage to the tanks those located on the house's surfaces.

Table 10: Common size of solar PV systems in Yemen

No.	Application	Capacity	Solar Panel No.*(Watt)	Inverter (kW)	Battery No.*(Ah)	Charge Controller (Ampere)	Average system price ($)[15]
1.	Residential-small size	20 W_p[16]	1*20	DC loads	1*7	-	36.7
		50 W_p	1*50	0.3	1*33	10	134
		100 W_p	1*100	0.5	1*40	10	207
		150 W_p	1*150	1	1*100	20	404
		300 W_p	2*150/3*100	1.5	1*150	30	666
2.	Residential-large size	1 kW_p	4*250/5*200	4	4*150	50	2800
		2 kW_p	10*200/8*250/7*300	3	5*200	50	3630
3.	Schools	300 W_p	2*150/3*100	1	1*150	30	575-611
4.	Pharmacies, barber shops and restaurants	300 W_p	2*150/3*100	1-2	1*150	30	611-721
5.	Grocery store, clothing store, bakery and electronics shop	100 W_p	1*100	0.5	1*50/ 1*70	20	234-264
6.	Institutions, Small Hotels, or Commercial Companies	1 kW_p	4*250	4	4*150	50	2800
7.	Mosques	300 W_p	2*150 /3*100	2	1*150/ 1*200	30	721-796
		500 W_p	2*250	1.6	2*150	50	1086
		1.2 kW_p	4*300	6	4*200	50	2880
8.	Health center	600 W_p	4*150/6*100	2	2*150/ 3*100	50	1210
9.	Police offices	150 W_p	1*150	0.5	1*100	10	337
10.	Irrigation pumps	18.5 kW_p	80*310	22	None	-	35000
		22 kW_p	126*205	24	None	-	40000
		26 kW_p	105*250	30	None	-	50000

[15] The prices are approximated and varies according to the time and quality of the products, and do not include the wiring and installations fees.

[16] Including small controller and 3 lamps.

5.2.1 Common prices of solar PV system components

A great diversity exists in the prices of solar power system components. This variety stems from the quality differences and technology types. Most Yemenis in fact cannot afford high quality products, and even sometimes average quality is regarded as expensive. In some cases, poor quality products do exist because of the economic considerations. Table 11 below shows the price ranges for each item according to results of undertaken interview.

Table 11: Price and type of solar PV components

Product name	Type	Price		Unit price	Life time
Solar Panel	Mono-Crystalline Silicon	0.6 – 1.28		$/$W_p$	10-25
	Poly-Crystalline Silicon				
Battery	Gel	1.5 – 3.4		$/Ah	1-3
	AGM	1.5 – 1.7			
	Car battery	0.7 – 1.2			
Charge Controller	PWM	0.92-.16		$/A	1-4
	MPPT for small systems	3.1-10			
Inverter	Pure Sine Wave	0.13 – 0.16		$/W	1-4
	Modified Sine Wave	0.07 – 0.1			
	UPS (Uninterruptible Power Supply)	0.14 – 0.16			
Wires (cross section)	1 mm^2	0.2		$/m	5-20
	1.5 mm^2	0.3			
	2.5 mm^2	0.8			
	4 mm^2	1.2			
	6 mm^2	1.6			
Accessories					
LED Lamps		AC	DC	$	1-3
	5 W	1.9	1.4		
	7 W	2.6	2		
	9 W	3	2.6		
	12 W	3.4	3		
LED TV (AC&DC)	17″	100		$	2-6
	19″	112			
	22″	132			
	24″	140			
	32″	184			

5.2.2 Warranties

After-sale services differ from one company to another. Most of the surveyed companies provide warranties for different periods. This period depends on the product brand and on who installs the system.

As most of the systems are small-scale, no service agreements are usually signed between the companies and customers. The follow-up and periodic maintenance services are not practiced for those systems and it is only limited to the manufacturing defects reported by the customers within warranty period.

Below are some examples of common warranties provided by companies or agencies in the local market:

- Solar Panels: A maximum of 20% reduction in the panel efficiency in the following 10-20 years (power output warranty).
- Batteries: 1-2 years for high quality brands, while low quality batteries have no warranties.
- Charge Controller and Inverters: 0.5-1 year only is usually provided.
- Irrigation water pumps: 2 years usually include periodic maintenance every 3 months.

5.2.3 Common Systems Failures

The low quality of products and improper design, installation, operation, and selection of equipment are the main factors affecting system reliability. Some improper designs, for example ignored system grounding and lack of proper ventilation, may cause failures and reduce the lifetime of systems. Many faults can be caused by incorrect component connections, such as directly connecting solar PV to a battery without charge controller in order to reduce the charging period, which can cause battery damages. The common failures of solar PV system components are summarized below:

- Solar panels: Discontinuity of charging processes or damage due to lightening.
- Batteries: Capacity degradation and significant decrease in the lifetime. Batteries are considered the first components that fail in the system.
- Inverters: Operation malfunctioning and high self-consumption or damage as a result of the inappropriate loading.
- Charge controllers: Reducing the charging current, causing long charging periods.

6 Recommendations for The Sustainability of Solar PV Market

PV market is currently strongly driven by the people's need for electricity. Aside from off-grid communities who fully depend on newly installed PV installations, there are unfortunately no strong mainstays to make this market sustainable for on-grid communities, where the circumstances to be altered and the electricity supply to be resumed. This is due to the fact that most solar PV systems are currently used merely for urgent loads like phone charging, lighting, etc., without covering a significant share of overall households' demand. Given the investment costs, low quality and poor durability of PV installations, people do not completely depend on this system. In order to make this market more sustainable and well established, some regulations and policies in addition to relevant programs should be implemented. The following points illustrate some of the needed measures based on stakeholders' inputs:

- Customs and tax exemptions: rates currently amount to 5% for custom duties and up to 10% for taxes. The exemption of these fees will encourage and attract investments in this sector, which will lead to a higher job creation in the local market and will reduce the financial burden for the government that the subsidized consumption of fuel and electricity implies.
- For long term planning and applicable to on-grid communities, adopting a legal framework and supporting policies such as net metering and other incentives would be a good foundation for the renewable energy sector to have the needed policies and legislative.
- Adopt codes and standards for renewable energy technologies.
- Increase the technical awareness in Yemeni communities, especially in rural areas.
- Certifying and capacity building for the installers and technicians of solar PV systems.
- Adopt quality assurance and market surveillance mechanisms.
- Working with the government to amend the specifications of the products related to solar energy and energy efficiency, as well as establish a laboratory to examine these products.
- Reform subsidy of the electricity tariff: the total reform of the subsidy is a political decision that may be taken when the general political situation and security conditions improve. It can be strongly discussed when the national grid electricity supply resumes.
- Create appropriate financing incentives and instruments for the investors and customers with a strong engagement of local banks.
- Distribute Solar Home Systems (SHS) for the poor people, especially for those who live in scattered villages with few households that are located far from the national grid such as top of mountains, where the access to electricity is unfeasible.
- Targeting critical services such as drinking water and health centers with appropriate support in order to be powered by solar energy.
- Hybridizing the existing diesel generators with solar energy to minimize diesel consumption, especially in off-grids areas.
- Creating new educational departments at universities and vocational institutes specialized in teaching renewable energy sciences.

- Establish research centers specialized in Renewable energy technologies and energy efficiency.
- Encourage the initiatives that seek to increase the local content and enhance SMEs positioning in the local markets, e.g. local manufacturing of the structural components of solar energy systems and the assembling of solar panels.

The aforementioned set of recommendations span across the adoption of appropriate regulatory and institutional frameworks, special programs targeting financial mechanisms, and the provision of capacity building initiatives. It can be championed by both relevant decision-makers in Yemen as well as stakeholders, such as international financial institutions, willing to actively get involved in the empowerment of the solar PV sector in Yemen.

Annex 1: Companies in the PV Business in Yemen

According to Musanadah Foundation for Development (M.F.D) and other sources[17], the following table lists the names of the main companies that are working in the solar PV technology in Yemen. It is worth mentioning that most of these companies provide high quality products and offer guarantees, maintenance and good after-sale services.

No.	Company Name
1.	Technical Solar Center(TSC)
2.	Abdulmajeed Alwahbani Group (ATG)
3.	Ghamdan Trading & Services (GTS)
4.	Power On
5.	Irena Electronics
6.	Abodiab for Trading & import, Al-Bakri Co.
7.	Abu Alrejal Trading Corporation
8.	Al-Alimi Importing
9.	Al-Hadha Trading & Agencies
10.	Alqabool for Trading & Cont.
11.	Al-Sadi Trading group,
12.	Al-Saleh Trading & Contracting Company,
13.	Alsonidar "Abdullah Hassan Alsonidar & Sons Group"
14.	Amin M. Alyamany & Bro.
15.	Basha Power Solutions
16.	Bin Yasin Trading
17.	Computer Engineering World (CEW)
18.	Delta Technology
19.	Future Computer Establishment
20.	Irena Corp,
21.	Mohammed Ali Alyamani & Bros.,
22.	Muthana Cooperation
23.	Natco Power
24.	Nawras Energy
25.	Net Technology
26.	Sam for Industrial supplies
27.	Sowaid Trading Import & Export co.
28.	Techno Gate
29.	Abdullah Ahmed Alkbous Brothers for Trading & Agencies
30.	Vienna for Trading & Constricting,
31.	Yemen Equipment and Supply & Alwadi Solar Co.
32.	Yemen Sun Foundation
33.	Yemen Trading & Construction Co.(ltd)
34.	Yemen International Technology – Ytech
35.	Alarabia

[17] Most of these companies participated in the first solar energy exhibition that holds on February 2016.

References

Al-Amal Bank. (2017). Branches Places. Alamalbank.com. Retrieved 16 March 2017, from http://www.alamalbank.com/index.php?option=com_content&view=article&id=213&Itemid=280&lang=en

AlHayani, (2016). Water crisis in Yemen – the forgotten war. Retrieved from http://www.al-yemeni.org/2016/01/17/%d8%a3%d8%b2%d9%85%d8%a9-%d8%a7%d9%84%d9%85%d9%8a%d8%a7%d9%87-%d9%81%d9%8a-%d8%a7%d9%84%d9%8a%d9%85%d9%86-%d8%a7%d9%84%d8%ad%d8%b1%d8%a8-%d8%a7%d9%84%d9%85%d9%86%d8%b3%d9%8a%d8%a9/

Alkuraimi Islamic Microfinance Bank, (2017). Alkuraimi Islamic Microfinance Bank - Home Page. Kuraimibank.com. Retrieved 16 March 2017, from http://www.kuraimibank.com/en/Default.aspx

Amideast. (2013). Promoting Youth Civic Engagement (PYCE) | AMIDEAST. Amideast.org. Retrieved 16 March 2017, from http://www.amideast.org/yemen/institutional-strengthening/promoting-youth-civic-engagement-pyce

Arab Union of Electricity. (2015). Statistical Bulletin (1st ed.). Arab Union of electricity. Retrieved from http://www.auptde.org/Publications.aspx?lang=en&CID=36

Al-Amal Microfinance Bank. (2016, August 10). Personal communication.

Al-Aolfe, M. (2011, May 22). Retrieved August 25, 2016, from http://www.sabanews.net/ar/news241781.htm

Al-Tayar, A. (2015, December 19). Retrieved 9 7, 2016, from http://www.althawranews.net/archives/363621

Al-Wahdawi. (2016, February 7). Retrieved from http://www.alwahdawi.net/news_details.php?sid=15225

Alwly, A. (2016, August 12). Yemenis turn to alternative energy amid power crisis. p. 2. Retrieved August 17, 2016, from www.al-monitor.com/pulse/originals/2016/08/yemen-war-power-cuts-solar-energy.html

Baharoon, D., Abdul Rahman, H., & Fadhl, S. (2017). Publics' knowledge, attitudes and behavioral toward the use of solar energy in Yemen power sector. Sciencedirect.com. Retrieved 16 March 2017, from http://www.sciencedirect.com/science/article/pii/S1364032115014938

CAC Bank. (2017). Branches. Cacbank.com.ye. Retrieved 16 March 2017, from http://www.cacbank.com.ye/newsite/go.aspx?page=75

CAC Bank. Written Communication, 20th February 2017.

Central Bank of Yemen, (2008). البنك المركزي اليمني. Centralbank.gov.ye. Retrieved 16 March 2017, from http://www.centralbank.gov.ye/ar/CBY.aspx?keyid=80&pid=74&lang=2&cattype=1

Central Statistical Organization (Yemen). (2013). Cso-yemen.org. Retrieved 16 March 2017, from http://www.cso-yemen.org/

FOA. (2017). About FAO | FAO | Food and Agriculture Organization of the United Nations. Fao.org. Retrieved 16 March 2017, from http://www.fao.org/about/en/

FAO. (2016). Situation Report. Fao.org. Retrieved from

http://www.fao.org/emergencies/resources/documents/resources-detail/en/c/431610/

General Authority for Rural Water Supply Projects (GARWSP), (2016). Solar energy water pumping station. Ministry of water and Environment -Yemen.

General Authority for Post and Postal Savings. (2016).

GIZ. 2014. Water Sector Programme Yemen. s.l

Hour news. (2016, June 26). Retrieved from http://hour-news.co/news-60432.htm

IFC. (2015). Market Assessments for Solar-Powered Irrigation Pumps in Morocco, South Africa and Yemen. Rome. Retrieved January 10, 2017, from http://www.fao.org/nr/water/docs/SPIS/10_Colback.pdf

Integrated Food Security Phase Classification. (2016). IPC analysis – Summary of findings, Acute Food Insecurity Current Situation Overview. Retrieved from

http://www.ipcinfo.org/fileadmin/user_upload/ipcinfo/docs/1_IPC_Yemen_June2016_AcuteFoodInsecurityAnalysis_CommunicationBrief.pdf

Ministry of Education. (2016). Personal communication.

Ministry of Electricity and Energy. (2016, 8). Personal communication.

Ministry of Industry and Trade. (2016). Personal communication.

National Information Center. (n.d.). Pupulation and Social Affairs. Retrieved September 5, 2016, from National Information Center: http://www.yemen-nic.info/sectors/popul/

Government planning to curb population growth. (2017). IRIN. Retrieved 16 March 2017, from http://www.irinnews.org/news/2008/07/14/government-planning-curb-population-growth

International Bank of Yemen. (2017). بنك اليمن الدولي - الصرافات ونقاط البيع. Ibyemen.com. Retrieved 16 March 2017, from https://www.ibyemen.com/ATM-Branch-Pos/%D9%86%D9%82%D8%A7%D8%B7_%D8%A7%D9%84%D8%B5%D8%B1%D8%A7%D9%81%D8%A7%D8%AA_%D8%A7%D9%84%D9%81%D8%B1%D9%88%D8%B9_%D8%A7%D9%84%D8%A8%D9%8A%D8%B9

Ministry of Agriculture and Irrigation. (2009). Annual Report. Retrieved from:

http://www.agriculture.gov.ye/?lng=english&

Ministry of Public Health & Population – Yemen and HeMAS, (2016). Service Availability and Health Facilities Functionality in 16 Governorates -Final report. World Health Organization.

Ministry of Public Health and Population, (2014). Annual statistic report.

Ministry of Industry and Trade, (2017). official website - Ministry of Industry and Trade - Republic of Yemen | Ministry of Industry & Trade. Moit.gov.ye. Retrieved 16 March 2017, from http://www.moit.gov.ye/moit/

Ministry of Legal Affairs, (2008). Law No. 21 of 2008 on the Bank Deposit Insurance Corporation (1st ed.). Ministry of Legal Affairs. Retrieved from http://www.centralbank.gov.ye/App_Upload/YemenDepInsLawJun08.pdf

Ministry of Oil and Minerals, (2017). yogc. Yogc.com.ye. Retrieved 16 March 2017, from http://www.yogc.com.ye/en/view.asp?id=1

Mutair, F. (2017). Questionnaire: Assessing the barriers and funding mechanisms for sustainable growth of solar PV in basic service sectors in Yemen. CAC Bank Head Office, Sana'a.

N.A. (2013). Yemen - Financial Infrastructure Development Project. Documents.albankaldawli.org. Retrieved 16 March 2017, from http://documents.albankaldawli.org/curated/ar/958711468154495470/Yemen-Financial-Infrastructure-Development-Project

NA. (2017). رحلة للخطوط الجوية اليمنية من عدن إلى السعودية..للمرة الأولى منذ عام ونصف العام. إرم نيوز. Retrieved 16 March 2017, from

http://www.eremnews.com/news/arab-world/yemen/555330

New Agriculturist: Country profile - Yemen. (2010). New-ag.info. Retrieved 15 March 2017, from http://www.new-ag.info/en/country/profile.php?a=1371

Observatory of Economic Complexity. (2017). OEC - Yemen (YEM) Exports, Imports, and Trade Partners. Atlas.media.mit.edu. Retrieved 16 March 2017, from

http://atlas.media.mit.edu/en/profile/country/yem/

OCHA, (2016). Yemen: Organizations 3W Operational Presence (as of 31 January 2016). OCHA. Retrieved from https://www.humanitarianresponse.info/system/files/documents/files/yem_3w_2016_01.pdf

Regional center for renewable energy and energy efficiency - RCREEE, (2016). Diesel to solar transformation - Second report (p. 45). Retrieved from http://www.rcreee.org/sites/default/files/d2s_rep_v7.1-31.3.16_web.pdf

SEMC, (2016). Economic Indicators Report Yemen (1st ed.). Studies & Economic Media Center SEMC. Retrieved from http://www.economicmedia.net/newen/images/english%20report%202016.pdf

SABA NET. (2016, March 8). Retrieved 8 August, 2016, from http://www.sabanews.net/ar/news421710.htm

Sharha, W. (2016, March 1). Retrieved August 25, 2016, from http://www.sampress.net/portal/news-15343.htm

Small Enterprise Development Fund . (2016). Personal communication.

Transparency International, (2016). Corruption Perceptions Index 2016. www.transparency.org. Retrieved 16 March 2017, from http://www.transparency.org/news/feature/corruption_perceptions_index_2016

UNDP. (2014). Policy Note: Prospects of Solar Energy in Yemen. (1st ed.). Retrieved from http://www.undp.org/content/dam/yemen/E&E/Docs/UNDP-YEM-Prospects%20of%20Solar%20Energy%20in%20Yemen-%20Policy%20Note.pdf

Yemen Reconstruction and Development Bank. (2016). Personal communication.

Tadhamon International Islamic Bank. (n.d). Personal Financing Services. Retrieved from

http://www.tiib.com/page.aspx?id=27

TIIB, (2017). Tadhamon International Islamic bank. Tiib.com. Retrieved 16 March 2017, from

http://www.tiib.com/page.aspx?id=27

USAID, Columbia University, School of International and Public Affairs, Capstone 2016 Report, (May 13th 2016). Using DCA's Loan Guarantee to Increase Energy Access in Africa. Retrieved February 22, 2017. https://sipa.columbia.edu/sites/default/files/USAID-Capstone_Final-Report_2016.pdf

UE, ACE International Consultants, (December, 2013). Feasibility study for the setting up of a Credit Loan Guarantee Scheme (CLGS) for Micro, Small and Medium Enterprises in Yemen. Retrieved February 23, 2017. http://yemennetwork.org/en/wp-content/uploads/2015/02/credit_loan_guarantee_feasibility_presentation_english.pdf

USAID, Development Credit authority. An Overview of USAID's Credit Guarantees. Retrieved February 24, 2017. http://pdf.usaid.gov/pdf_docs/pdacx987.pdf

US Embassy. (2012). U.S. Government Assist in Rehabilitation of Sana'a School. Retrieved from

https://yemen.usembassy.gov/ugars.html

UNOCHA. (2017). Humanitarian Need Overview Yemen

UNFCCC. (2015). Intended Nationally Determined Contribution (Indc) Under The UNFCCC. (1st ed.). Retrieved from http://www4.unfccc.int/submissions/INDC/Published%20Documents/Yemen/1/Yemen%20INDC%2021%20Nov.%202015.pdf

WEC, Water and Environment Center. 2016. Feasibility Study of Solar Photovoltaic Power Plant for Operating 50% of SWWTP. 2016.

WHO EMRO | 2017 | تزايد معاناة مرضى الفشل الكلوي مع تفاقم الأزمة الصحية في اليمن - Arabic | النشرات الاعلامية. (2017). Emro.who.int. Retrieved 15 March 2017, from http://www.emro.who.int/ar/2017-arabic/kidney-patients-struggle-as-yemeni-health-crisis-worsens.html

World Health Organization, (2015). Yemen: Sanitation, drinking-water and hygiene status overview (p. 4). UN-water global analysis and assessment of sanitation and drinking water. Retrieved from http://www.who.int/water_sanitation_health/monitoring/investments/yemen-10-nov.pdf?ua=1

World Health Organization. (2016). Health System in Yemen - Infographic. Retrieved from http://www.who.int/hac/crises/yem/sitreps/yemen-herams-infographic-november2016.pdf?ua=1

Yemen Commercial Bank. (2017). Addresses of Branches. Ycb.com.ye. Retrieved 16 March 2017, from http://www.ycb.com.ye/ycb_new/ycb-en/DisplaySectionDetail.aspx?id=114

Yemen Ministry of Public Health and Population. (2011). Annual Statistical Health Report. Retrieved from http://www.moh.gov.ye/arabic/docs/Report2011.pdf

Yemen Ministry of Public Health and Population. (2012). Annual Statistical Health Report. Retrieved from http://www.moh.gov.ye/arabic/docs/Report2012.pdf

Yemen Ministry of Public Health and Population. (2013). Annual Statistical Health Report. Retrieved from http://www.moh.gov.ye/arabic/docs/Report2013.pdf

Yemen Ministry of Public Health and Population. (2014). Annual Statistical Health Report. Retrieved from http://www.moh.gov.ye/arabic/docs/Report2014.pdf

Yemen Times, "Sana'a girls' school completes month-long renovations", 18 October 2012. Retrieved from

http://www.yementimes.com/en/1617/news/1538/Sana%E2%80%99a-girls%E2%80%99-school-completes-month-long-renovations.htm

Yemen Standardization, Metrology and Quality Control Organization, (2017). YSMO - Yemen Standardization, Metrology and Quality Control Organization. Iso.org. Retrieved 16 March 2017, from https://www.iso.org/member/2203.html

Zaabal, A. (2017). مدينة الروضة محافظة شبوة اول مدينة في اليمن تنور شوارعها عبر الطاقة الشمسية. Adenalhadath.net. Retrieved 16 March 2017, from http://adenalhadath.net/news_details.php?sid=17232

مرصد البرلمان اليمني. (2009). قانون رقم (15) لسنة 2009م بشأن بنوك التمويل الأصغر. Retrieved 16 March 2017, from http://www.ypwatch.org/page.php?id=1152

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