Reduction of Carbon Dioxide Emissions by Using Photovoltaic Systems in the Syrian Arab Republic

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Abstract: Syria is one of the developing countries in which photovoltaic systems were first installed as navigation aids along the Syrian coast. Since then the use of photovoltaic systems is being widely spread in size and type such as stand-alone systems in remote areas and grid-connected systems. This paper presents a survey on photovoltaic systems, their applications in Syria by the end of 2013, and it illustrates that reduction in carbon dioxide emissions can be accomplished by using photovoltaic systems. It shows how many tons of CO_2 emissions could be avoided by using photovoltaic systems (stand-alone, gird connected) instead of fossil fuels for either generating electricity or replacing kerosene lamps.

Keywords: CO_2 emissions, PV stand-alone systems, grid-connected systems, diesel generator.

1. INTRODUCTION

Increasing the negative effects of fossil-fuel combustion on the environment in addition to limited stock have forced many countries to explore and change to environmentally friendly alternatives that are renewable to sustain the increasing energy demand.

The total peak power of PV systems installed in Syria was developed from less than 80 kWp by the end of 1990s to about 246kWp by the year 2013, all systems were stand-alone and grid-connected ones. Photovoltaic system component industry has been established in Syria in 1997 by the Higher Institute for Applied Science and Technology (HIAST) which opened the doors to many manufacturing companies to take part in the installation of such systems.

At present, there are many villages and remote areas located far away from the Syrian electricity networks. Economically connecting these areas to the grid is unacceptable, owing to its low population, and the little amount of energy required. In the past these facts dictated the use of diesel generators as a source of power supply or kerosene lamps for lighting.

The diesel generators are being used in many countries as a power supply for rural areas, but it was found that they are not suitable for remote areas, as they need maintenance, skilled personal which is not available for low populated areas. The high running cost and low reliability made this option unpreferable for developing countries.

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Photovoltaic effect, which is the direct conversion of solar energy to electricity, may be the most reliable source for rural electrification in the developing countries. But the utilization of PV systems considered as a new technology for developing countries has some obstacles.

The use of PV systems reduces the fossil-fuel consumption and greenhouse-gas emissions. The PV systems require energy related to construction, operation and decommissioning. This energy must be small compared with the energy produced from the system in its lifetime.

2. PV APPLICATIONS IN SYRIA

There are five main types of PV applications in Syria; PV application for rural electrification, street lighting, grid-connected PV systems, navigation aids, and water pumping. Table **1** shows the total installed capacity of PV systems in Syria [1], (Figure **1**) shows some of PV systems installed in Syria.

2.1. Rural Electrification with PV Systems

The Problems which face the electrification of all rural regions in any country and which have low population, and far from the electric networks, make the electric network very expensive to extend high line voltage through desert to electrify few hundred inhabitants.

The use of PV systems for rural electrification started by electrifying 4 remote villages near Aleppo with a total capacity of 53kWp. International agencies such as United Nations Development Program (UNDP) and Japan International Cooperation Agency (JICA) cooperated to introduce PV technology into the

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Table 1: The Total Installed Capacity of PV Systems in Syria

Type of System		Total Power [kWp]
Stand- alone systems	Electrification (4 villages)	53
	Desalination system	10
	Navigation aids along the Syrian coast	2.5
	Street lighting	7
	PV systems for earthquake monitoring stations	10
	Hybrid systems (PV+Diesel)	32
	Pumping systems	31
	Other applications (portable systems,…)	31
Grid connected Systems		70
Total		246.5

Figure 1: PV Systems installed in Syria.

country. The cooperation resulted in installing the following systems [1]:

- A centralized PV power plant with a capacity of 35 kWp to electrify 44 houses in Zarzita village.
- Small-scale centralized PV system with a capacity of 3.6 kWp to electrify 6 houses in Abou-surra village.
- Individual stand-alone PV systems of various capacities (50~350W/DC, 500W/AC for each system) to electrify 66 houses in the villages of Mesherfeh, Fedre, Katoura, and Rasem Al-sheikh Khalif.

2.2. PV Pumping and Desalination Systems

Water pumping was considered as one of the best PV applications for human and livestoke in rural places. The water pumping projects consists of [1]:

- A PV station of 5kW capacity for pumping up and transferring drinking water into the Zarzita village.

- A PV station of 10kW capacity for pumping and desalinating brackish water using Reverse Osmosis (RO) technology in the village of Rasem Al-sheikh Khalif.
- 3 pumping systems in Al badiah near Palmyra with 2 kWp capacity each.
- 4 pumping systems near Palmyra with capacity of 5 kWp each.

2.3. Street Lighting Systems

LED Street lighting PV systems was started in 2010 near Lattakia, where 47 systems were installed with a total capacity of 4.7kWp. Many systems are installed in Ministry of Electricity with total capacity of 2.3kWp.

2.4. Monitoring and Navigation Aids

The photovoltaic conversion as an electric power source has been started in Syria in 1993 where the first PV system was installed to supply light houses along the Syrian coast with a capacity of 2.5kWp. A hybrid system (PV and diesel) was installed with a capacity of 32kWp to supply a civil aviation station in Altanf area in 2005. The PV systems for earthquake monitoring stations project were installed in 2006, consisting of 27 PV systems with a total capacity of 10kWp.

2.5. PV Grid-Connected Systems

The PV applications increased in size and type; the first PV grid- connected system was installed on the roof of the Ministry of Electricity in Damascus with total capacity of 70kWp.

The total PV system installed in Syria was 246.5kWp by the end of 2013.

3. ESTIMATED CO_2 EMISSIONS

In general, over its 30-year expected lifetime of PV systems, a 1kWp system is considered to reduce CO_2 emissions equivalent to planting 145 trees. (Based on typical utility pollution, it will prevent emissions of 37.5 ton of CO_2, 164.6kg of SO_2, and 53kg of NO_2). It would produce 46538kWh of electricity, as much as would be generated by burning 22.6 ton of coal.

3.1. PV Compared to Small Diesel Generators

Diesel fuel has a density of about 0.78kg/lt. Diesel fuel is a mixture of hydrocarbons with an average weight ratio of 12 parts of carbon to 2 parts of hydrogen with small amounts of other elements like sulfur. Therefore, 1 liter of diesel fuel has 0.67kg of carbon and will produce 2.7 kg of CO_2. Based on survey of web sites for the specifications of diesel generators, let us consider the generator L90AE 9 hp Unit. This generator would produce 5 kW continuously using about 1.9 liter of diesel fuel per hour. The generator will produce about 2.63kWh/lt of fuel used, which gives an easy to remember number of 1kg of CO_2 produced for each kWh of electricity produced [2].

3.1.1. Stand-alone PV Systems

A typical off-grid PV system in general has a capacity of 1kWp for average weather conditions in Syria, such a system would produce about 4 kWh/d and 1460 kWh/ y. This system would mitigate 1.46 ton of CO_2 per year. Over the 30-year lifetime of the system (since PV modules fabricated in Syria with a 30-year guarantee), that adds up to 43.8 tons of CO_2.

The total capacity of stand-alone PV systems installed in Syria is 176.5 kWp. These systems would mitigate 7730 tons of CO_2 over the 30-year life time of the systems. Recently there has been a good deal of interest in the concept of "buying the right" to emit carbon dioxide. There is even an International Carbon Bank and Exchange; and the price of CO_2 emission mitigations is expected to be soon about18 $/ton. Using the example above, a large multinational corporation may be willing to pay at least $139,140 for the CO_2 saved by stand –alone systems installed in Syria.

3.1.2. Grid Connected PV Systems

Commonly installed in Syria 1 kWp PV systems would produce about 4.6 kWh/day and 1679 kWh/year of electricity; such a system would mitigate 1.679 tons of CO_2 per year. Over the 30-year lifetime of the system this adds up to 50.4 tons of CO_2.

The total capacity of PV grid-connected systems installed in Syria is 70 kWp. These systems would mitigate 3526 ton of CO_2 with a cost of $ 63468 for the CO_2 saved.

3.2. PV Compared to Kerosene Lamps

The calculation is more difficult to quantify since the amount and quality of light from a PV powered fluorescent lamp is quite different from poor quality, yellow illumination from the typical kerosene lamp. Therefore, the PV array with two 20 watt fluorescent lamps in home simply replaces two kerosene lamps, one per room, without attempting to match illumination (the rooms are very much brighter after the PV system is installed). Also assuming that the house would have been using about 250 ml/day of kerosene.

Kerosene has a density of 0.84kg/lt [3], slightly higher than diesel fuel but the same type of calculation applied, giving 2.6kg of CO_2 emission for each liter of kerosene burned [4].

CO_2 emmision factor = Kerosene Density × Energy Density × CO_2—Coversion (A1)

Kerosene density = 0.840kg/lt,

Energy density = 12kWh/kg (DIN18230-3),

CO_2-conversion = 0.2676kg CO_2/kWh (IWO—Institute furwirtschaftlicheOlheizunge. V.)

Produced CO_2/year (kg) = 365 × CO_2 Emission factor × Kerosene Consumption/day (A2)

This adds up to 237.25kg/year for the 91.25 liters of kerosene eliminated by installing the 100W PV system. Over the 30-year lifetime of the system, there are 7.12 tons of CO_2 mitigated with a price of $128.

4. CO_2 EMISSIONS FROM FABRICATION AND INSTALLATION OF PV SYSTEMS IN SYRIA

Production and installation of a PV system can be divided into two sectors in Syria:

- Fabrication and packaging of the solar cells to create a PV panel,
- Installation of many panels to form a PV system.

4.1. Cell Fabrication and Packaging to form a PV Panel

Panel formation entails the cells are connected into strings with copper tabs the lamination of the cells behind glass with EVA and Tedlar using heat and pressure. A junction box is mounted on the back of the panel. The considered plastics consumption for module encapsulation (1kg/m^2 EVA, 0.5kg/m^{2}PVF/PET, 0.3kg/m^2 other) [5]. In most cases, an aluminum frame is placed around the panel perimeter. The aluminum frame (1.6kg/panel) represents a significant fraction of the panel's embodied energy; determination of the energy content of aluminum is difficult, since it depends on the fraction that is recycled, determination of the CO_2 content is also difficult. Table **2** gives an overview of the primary energy requirements and the resulting CO_2 emissions of different materials used in forming the PV panel. As can be seen, recycling has a major effect on the energy requirement and CO_2 emission of materials. For aluminum the savings can reach 95%, while recycled aluminum requires less energy than new. For each PV-panel formation in Syria the average CO_2 emission mitigated is equal to 19kg.

4.2. Balance of Systems and Installation

The balance of system (BOS) comprises wiring, power electronics, foundations, support frames, transport and installation. Of these, the support frames and foundations are by far the most energy intensive. In a system installed in an open field, the foundations are typically concrete while the support frames are steel. Both of these materials are energy and CO_2 delicate (see Table **2**). In a system installed on a building roof, the foundations can generally be dispensed with. In addition, if the PV array forms part of

Table 2: Materials Used for the Manufacturing of PV Power Plants (Without Solar Cells), their Energy and CO_2 Intensity

Material	Energy Requirements (kWh/kg)	CO2 Emissions (kg/kg)	References
Aluminum (new)	53.0–245.0	15.1–18.8	[6,7]
Aluminum (50% recycled)	31.4	6.7	[8]
Concrete	0.17	0.14	[9]
Copper (40% recycled)	24.6	5.08	[8]
EVA	20.8	2.34	[10, 11, 12]
Glass (new)	4.1	0.54	[9]
PVT (Tedlar1)	31.9	2.05-2.05	[10, 11, 12]
Steel (new)	8.3	3.0	[8]
Steel (40% recycled)	5.6	1.7	[8]

the roof structure then the energy embodied in the displaced roof components can be set against the embodied energy in the PV array.

It is difficult to estimate the energy savings possible by displacing roofing materials with PV panels, because many different types of roofing materials are in common use. For example, an aluminum facade could be replaced with a PV facade, saving large amounts of energy because aluminum is an energy intensive material. On the other hand, coated steel has relatively low related energy.

CONCLUSIONS

PV currently appears an expensive option for producing electricity compared to other energy sources. Syria supports this novel technology; its promising future potential and the additional benefits are already effective at present. The introduction of renewable energy technologies in Syria results into several positive aspects:

1) The reduction of fossil fuels.

2) The reduction of CO_2-emissions.

3) Additional revenues, due to the possible certificates (carbon credits) of the avoided CO_2-emissions.

The price of fossil fuels will go up and clean energy alternatives such as solar, along with efficiency, will become the primary means by which any country should meet its targets for reducing CO_2 emissions.

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