ECONOMIC ASSESSMENT OF THE USE OF SOLAR ENERGY IN KUWAIT

Mohamed A. Hadi, Council of Ministers, Kuwait
Refaat H. Abdel-Razek, Arabian Gulf University, Bahrain
Walid M. Chakroun, Kuwait University, Kuwait

ABSTRACT

In Kuwait, the current method of generating electricity using conventional power plants cannot provide beneficiaries with adequate service unless more plants are constructed. In addition to their high cost, these plants cause environmental damage, creating the need to investigate sources of clean energy. This study assesses the technical and economic feasibility of implementing Photovoltaic (PV) solar energy in residential houses in Kuwait. Data and information were collected and the appropriate PV system was selected according to cost and PV specifications. Next, the equivalent annual costs of the PV system with various discount rates were estimated together with the cost per kWh both for new and existing houses. Third, the annual reduction of CO_2 emissions resulting from implementing grid-tied PV systems was calculated. Taking into consideration the financial savings from CO_2 reduction, the cost per kWh was estimated and compared with the current cost. The purported discount rate adopted by the Kuwaiti government's long term plan is 6.7%. However, a range of discount rates from 0% to 20% was applied and results obtained. The results showed that with a 6.7% discount rate the annual savings on energy costs for a new house and a previously constructed hose were KD 745 and KD 653 respectively. The results also revealed the payback periods for the PV system for these houses are 7 and 7.4 years respectively. We concluded that integrated PV (BIPV) solar energy is economical and technically feasible in Kuwait when the discount rate is equal to, or less than, the break-even point of 10.36%.

JEL: N7

KEYWORDS: BIPV, Equivalent Annual Cost, Payback Period, Renewable Energy, and Solar Energy.

INTRODUCTION

Energy consumption in Kuwait is increasing at an 8% yearly rate (Alotaibi, 2011). Population growth has resulted in the need for new infrastructure, especially in forms of electricity and water. This has doubled the loads of electrical power plants, and creates challenges to find alternative sources of electrical power. Residential buildings consume a high percentage of electricity and can reach 70% of total production during the summer (MEW, 2010). The current method used to produce electricity cannot effectively provide beneficiaries with acceptable service throughout the year, unless more new conventional power plants are constructed (Al-Faris, 2002). Conventional power plants are major oil consumers. The consumption in these plants alone would reach 26.5% of total Kuwaiti oil production by 2020. With the oil production rate of 2008, all the produced oil would consumed locally by 2027 (Alotaibi, 2011).

Kuwait is considered one of the highest carbon dioxide emitters for each person in the world (30.2 ton a person). This occurs mostly because of gases emitted from conventional electricity plants (UN data, 2010). Emissions of toxic gas from traditional power generators, which run on fossil fuels, are harmful to the environment and humans alike. Because of these circumstances, there is a growing interest in renewable and eco-friendly energy sources such as solar. Solar energy is a renewable energy sources that can be a partial substitute for fossil fuel thereby avoiding most of the negative impact of fossil fuels

(Kumar and Tiwari, 2009). Photovoltaic (PV) technology is proven and easy to use and the global PV market is predicted to increase substantially in the future (Hoffmann, 2006).

LITERATURE REVIEW:

There are several reasons to strengthen the research results and to decrease future risks when utilizing PV technology. Efficient and accurate data from recent studies will help overcome any unexpected entries to the PV in the future. Efficiency of the solar modules is increasing while manufacturing and selling prices are decreasing (Al-Salaymeh, et al., 2010). The average estimated payback time (EPBT) is from 3.25 to 4.5 years for most silicone types of solar (Seng, et al., 2008). The prices of BIPV can be effected by many causes. Sunny and clear locations are more compatible with the PV Modules, which can lessen the cost and increase the PV modules efficiency. Choosing locations and orientations with higher incident solar irradiance can be a key for PV technology applications (Laleman, et al., 2011), and (Hoffmann, W., 2006). Kuwait's annual solar irradiation estimated at 2,100–2,200 kW/m^2 a year (Ramadhan, et al., 2011). The size of the PV directly effects both the cost and the technical factors. The larger the PV the more feasible it is both technically and economically. Cost reductions resulting from larger production volumes affect feasibility (Zahedi, 2006).

Fossil fuel prices influence solar energy preference. The higher the fossil fuel prices the higher the utility tariff cost and production cost of conventional electricity. This in turn encourages the trend toward intensive use of solar energy. Grid-tied PV have a total cost far lower than the off-grid PV or standalone PV, because of added batteries, battery chargers, and a current regulator (Al-Salaymeh, et al., 2010)].

Depletion of all sources of fossil fuel within an average of 50 years forces us to invest more heavily in sustainable sources of energy like solar (Kumar S., 2009). CO2 emission has a cost subtracted from the BIPV cost. 33 US$/ton of CO2 mitigation represents the monetary value of one carbon credit for mitigation of 1 ton of CO2 emission (Chel, et al., 2009). The use of PV power can significantly reduce the summer demand peaks where the load for midday air-conditioning demand increases (Rüther, et al., 2008). From economic analysis, the life cycle cost of PV energy is lower than the life cycle cost of conventional electricity in some regions. PV has significant advantages when there are no utility cables, because cabling is expensive and installation can be a time consuming process (Bhuiyan, et al., 2000). Small-scale rooftop applications (1-100 kW) do not take up new land, which could be a huge advantage considering high urban population density in Kuwait. In comparison to large-scale PV plants, there is no need for more transmission lines, lowering both the cost and time of installation. When small-scale PV become economically viable, they can considered a rather low risk long-term investment (Zahedi, 2006).

DATA AND METHODS

Kuwait is a desert country with a clean, hot and dry climate. From the NASA clearness index, K_T, the average yearly reading for Kuwait over a twenty-year period is 0.59, which represents clear skies almost year long. For values above 0.5, the location has clear skies most days of the year (Islam, et al., 2009). The maximum yearly total global solar radiation matches a tilt angle of 30°, which is equal to Kuwait's latitude. The PV arrays for a proposed PVsystem should have the same orientation, 30° angle facing south (Al-Hasan, et al., 2004). The maximum annual sun hours for Kuwait are 9.2 hours daily. With average peak hours of 7.5 daily, average solar radiation of 5.5 kW/m^2 . The diffused radiation of 1.6 kW/m^2, where only 1 kW/m^2 would normally needed to activate the solar cell to its maximum power (Alnaser et al., 2004).

Al-Mumin and Al-Mohaisen (2008) showed the average roof area of a typical Kuwaiti house is 308.3 m2, as shown in Fig.1. The average Kuwaiti house consists of two and a half floors, and consumes an average of 166.25 MW/yr (MEW, 2009). The latest MEW report (2010) stated there are 375,529 houses or residential consumers. The cost of producing electricity in Kuwait is 34 Fills/kWh ($0.12/kWh) (Ramadhan and Nasseeb, 2011).

Figure 1: First Column Represents the Average Roof Surface Area of Kuwaiti Houses

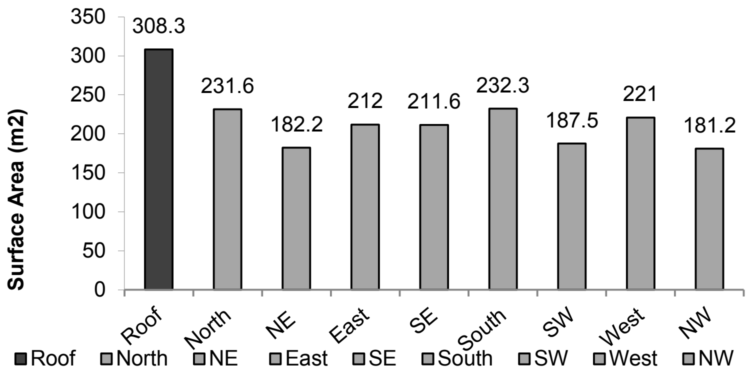

Figure (1) showed the average roof areas of the Kuwaiti residential houses of 308.3m^2 with all facades average areas considered . (Source: Al-Mumin and Al-Mohaisen, 2008)

Selecting the proper module depends on several issues. Maximum efficiency, minimum area, lowest cost modules are desirable. The specification data of four different types of PV modules (Samsung, 2011, DMSOLAR, 2011, SinoSolar 2011 and BestSun 2011) are collected. Hadi (2011) analyzed these data and concluded the BestSun156P300-72 module is the most suitable for Kuwait. Table 1 presents the main comparison features between the four modules, some specific data for each module and the comparison results.

Electricity supply in Kuwaiti uses 3-phase power, which leads us to select a model TLS-ZB 40kW inverter unit. The cost of the inverter is $8,810, with a twenty-year manufacturer's warranty (Tresstech, 2011).

Table 1: Comparison of Four Different PV Modules

Features	Samsung LPC241SM	DM Solar DM-280M2-3	SinoSolar SA260-96	BestSun 156P300-72
Cell Type	Mono-crystalline	Poly-crystalline	Mono-crystalline	Poly-cristalline
Efficiency	15.06%	14.40%	NA	15.6%
Module Output Wattage	241	280	260	300
Module Price $	582	518	429	465
Price/Watt $	2.41	1.85	1.65	1.55
NOCT	46+2C	47+2C	NA	46+2C
Weight	18.6 Kg	23.2KG	NA	13 Kg
Temp. Cycling	-40 to +85C	-40 to + 90C	NA	-40 to +85C
Roof Area m2	308.3	308.3	308.3	308.3
Occupied Area (ms)	1.60066	1.940352	1.659	1.940352
Total AAPM plus shade	2 m2	2.3 m2	2 m2	2.3 m2
No. of Modules	154	134	154	134
System Power Watt	37,114	37,520	40,040	40,200
Cost of Modules $	89,444.74	69,412	66,066	62,310

Table (1) represents a comparison of four PV Modules; BestSun156P300-72 is the chosen Module for number of reasons. It has the highest Efficiency of 15.6%, the highest manufacturing power of 300 Watt, and the lowest cost by watt $1.55.

BOS of a PV consists of all the technical and engineering parts. It mainly consists of an inverter to transform the direct current (DC) power from the PV array into a form of alternating current (AC) electricity that can combined with, and connected to, the electric utility grid. It also involves support structures and the cost of labor for the PV installation. The BOS accounts for 30% to 40% of the cost of the PV. In some studies, 35% is chosen as the average BOS cost of the PV. Usually, the cost of the inverter, is the second most expensive part added to the module cost, thus decreasing the BOS cost from 35% to 25% (Ayompe, et al., 2010).

RESULTS

Estimating the PV Initial Cost

The roof area of the average residential house is 308.3m^2. Each module of the selected model BestSun156 P300-72 occupies 2.3m^2 including the shaded area between module panels. We compute the number of modules per PV system as follows = total roof area / area of a single module= 308.3m^2 / 2.3m^2 = 134 modules per house. The initial cost of one module with 300-watt peak output power = $ 465 (Table 1). The initial cost of all modules= $465 * 134 = $62,31. The initial cost of the inverter is$8,810/system (Tresstech, 2011).

The BOS Initial Cost and Total PV System Initial Costs per House is computed as follows:

System initial cost = modules initial cost + inverter initial cost + BOS initial cost (1)

Its assumed that the cost of BOS equals 25% of the system cost (Rigter and Vidican, 2010). Let x = the initial cost per system in equation (1). Then x = $62,310 + $8,810 + 0.25x → 0.75x = 71,120 and x = 71,120 / 0.75 = 94,826.7. BOS initial cost = $94,827 * 0.25 = $23,707 per house. Thus the total PV system initial costs *Ai* = $94,827 / house

Estimating the Equivalent Annual Cost (EAC) of The PV System

The cost of operations and maintenance (O&M) is estimated next. We use the following equation (Park, 2009):

$$AAOM = P*(1+f)n \tag{2}$$

Where: *AAOM* is the average annual cost of operation and maintenance, *P* is the present O&M cost (System data manual) = $500, f is the annual inflation rate expected = 3.24% (InflationData.com, 2011), and *n* is the system estimated useful life =20 years. Then, *AAOM* = $688.40

The Total Equivalent Annual Costs (EAC) is estimated as follows:

$$EAC = Ai + AAOM \tag{3}$$

Where: *EAC* is total system equivalent annual cost, *Ai* is the equivalent annual cost of the system initial cost at certain discount rate (*i*) and is derived from the following equation:

$$Ai = P * CRF \tag{4}$$

Where: *P* is the system initial cost, *CRF* is the capital recovery factor and is obtained from the following equation:

$$\boldsymbol{CRF} = \left[\frac{\boldsymbol{i}\times(\mathbf{1}+\boldsymbol{i})^{\boldsymbol{n}}}{(\mathbf{1}+\boldsymbol{i})^{\boldsymbol{n}}-\mathbf{1}}\right] \tag{5}$$

Where: i is the discount rate and n is the system useful life, assumed to be 20 years.

The purported discount rate adopted by the Kuwaiti government's long-term plan is 6.7%. However, discount rates from 0% to 20% applied are. The resulting *EAC*s in US$ and Kuwaiti Dinars (KD) given in Table (2).

Table 2: *EAC* of BIPV with Different Discount Rates

Discount rate	Initial cost ($)	The Capital Recovery Factor *CRF*	Initial cost per/year ($)	O&M/year ($)	System *EAC* ($)	System *EAC* (KD)
0%	94,827	0.05	4,741.3	688.4	5,432.0	1,514.4
5%	94,827	0.0802	7,609.1	688.4	8,297.6	2,313.4
6%	94,827	0.0872	8,267.4	688.4	8,961.2	2,496.9
6.7%	94,827	0.0922	8,743.3	688.4	9,431.8	2,629.6
10%	94,827	0.1175	11,138.3	688.4	11,826.7	3,297.3
15%	94,827	0.1598	15,149.7	688.4	15,838.1	4,415.7
20%	94,827	0.2054	19,473.3	688.4	20,161.7	5,621.1

*Table (2) shows the equivalent annual cost (EAC) which equal to the initial cost multiplied by the capital recovery factor at certain discount rate added to it the average operating and maintaining cost of the PV system during its lifespan. * 1US dollar = 0.2788 Kuwaiti Dinar (KD) ** 1 Kuwaiti Dinar (KD) = 3.586 US dollars*

System Annual Output Power (AOP) and Cost Per kWh

Table (3) shows the cost/kWh at several discount rates in US cents and KF. The annual output power is estimated using the following equation (Ramadhan and Nasseeb, 2011)

$$AOP\ in\ Kuwait = average\ insolation\ /m2/yr\ *\ module\ efficiency\ *\ modules\ area \qquad (6)$$

The average annual solar insolation for Kuwait = 2,080 kWh/m^2/yr (Ramadhan and Nasseeb, 2011 & Alnaser, et al., 2004), The module efficiency is 15.6% (BestSun, 2011). The area occupied by 134 modules is 134 * 1.94 m2 (Table 1) = 259.96 m^2

AOP in Kuwait = 2,080 kWh/m^2/year * 0.156 * 259.96 m^2 = 84,351.8 kWh/yr. So the cost of electricity per kilowatt hours is calculated using the following equation:

$$Cost\ of\ electricity\ per\ kWh = EAC/AOP \qquad (7)$$

Cost of electricity per kWh (at 0% discount rate) $= \frac{1{,}514.4\ KD}{84{,}352 KW/yr}$ = 18 KF/kWh

1KD=1000 Kuwaiti Fils (KF)

System Net Cost After Deducting the CO2 Cost/kWh

Table 4 shows the net system cost per kWh at several discount rates. CO_2 emission has a cost; this cost ranges widely, depending on several factors (Roberto, 2010). In this study the average cost of CO_2 emission is $30/ton (Ramadhan and Nasseeb, 2011; Chel, et al.; 2009; Johnson and Keith, 2004). The amount of CO_2-e prevented by the use of solar energy is given (EPA, 2011) as:

$$Annual\ amount\ saved\ of\ CO2\ per\ kWh = 7.18*10\text{-}4\ metric\ tons\ CO2/kWh \qquad (8)$$

$= (7.18 \times 10^{-4})$ metric tons CO2 per kWh × 84,351.8 kW = 60.6 metric tons/house/year

Cost of CO_2 saved by the PV system = 60.6 * $30 =$1,818/house (KD 507/house)

Cost of CO_2 saved per kWh = Annual cost of CO_2 / PV system annual output power = $1,818 / 84,351.8 kWh = $0.022/kWh (KF 6.1/kWh)

Net cost per kWh (at zero interest rate) = EAC per kWh – CO_2 cost per kWh = 18 – 6.1 = KF 11.9 /kWh

Table 3: Cost per kWh for the BIPV System At Different Discount Rates

Discount rate		0%	5%	6%	6.7%	10%	15%	20%
System EAC	US $	5,432	8,298	8,956	9,432	11,827	15,838	20,161
	KD	1,514	2,313	2,497	2,630	3,297	4,416	5,621
System AOP (kWh/house)		84,352	84,352	84,352	84,352	84,352	84,352	84,352
Cost/kWh	US Cent	6.4	9.8	10.6	11.2	14.0	18.8	23.9
	KF	18.0	27.4	29.6	31.2	39.1	52.3	66.6

*Table (3) represents the PV System cost per Kilowatt at different discount rates in both Kuwaiti Fills (KF) and US Cents (US ¢). * 1US dollar = 0.2788 Kuwaiti Dinar (KD) ** 1 Kuwaiti Dinar (KD) = 3.586 US dollars*

Cost Comparisons between PV and Current Systems

The current electricity cost in Kuwait is 34 KF/kWh (Ramadhan and Nasseeb, 2011). The discount rate adopted by the Kuwaiti government's long term plan is 6.7%. The cost per house at a 6.7% discount rate using PV system is 2,123.5 KD/house. The current annual cost equals Cost/kWh * Annual PV system output = 34 * 84,351.8 = 2,868 KD/year. So the annual saving per house equals 2,868 – 2,123.5 =744.5 KD/house.

Table 4: Cost Comparisons between PV & Current Cost for a New House

Discount rate	PV system cost/kWh	PV System annual cost/house	Conventional cost/kWh	Conventional annual cost/house	Cost Differences KF/kWh	PV Annual output power	Annual Cost differences KD/house
0%	11.9	1,007.7	34	2,868	22.1	84,351.8	1,860.3
5%	21.4	1,807.3	34	2,868	12.6	84,351.8	1,060.7
6%	23.6	1,990.8	34	2,868	10.4	84,351.8	877.2
6.7%	25.2	2,123.5	34	2,868	8.8	84,351.8	744.5
10%	33.1	2,791.2	34	2,868	0.9	84,351.8	76.8
10.36%	34.0	2,868.0	34	2,868	0.0	84,351.8	0.0
15%	46.3	3,909.6	34	2,868	-12.3	84,351.8	-1041.6
20%	60.6	5,115.0	34	2,868	-26.6	84,351.8	-2247.0

Table (4) shows the final cost comparisons between the PV system and current system per kWh and per house per year for several discount rates.

Figure 2: Cost Differences per kWh between PV and Conventional Systems

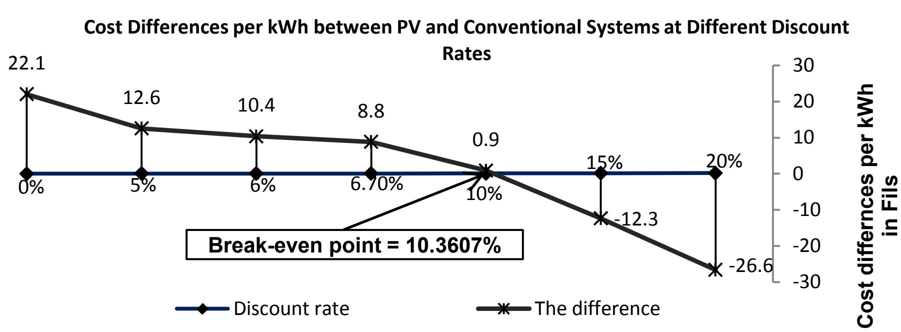

Figure (2) shows the cost differences of the kWh between PV system and conventional system at different discount rates.

Figure 3: Annual Cost Differences per House at Different Discount Rates

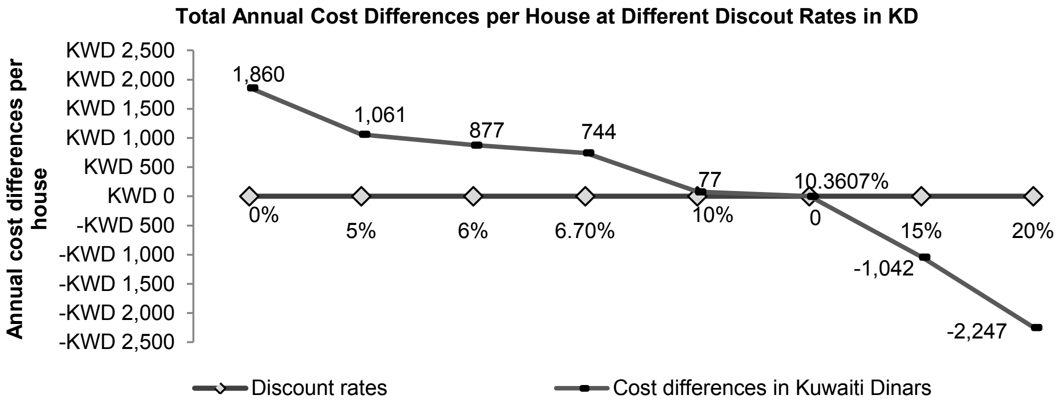

Figure (3) shows the annual cost differences per house at different discount rates. It is shown that the PV system is economically feasible when the discount rate is less than or equal to the break-even point of 10.36% discount rate.

<u>System Pay-Back Period for Newly Constructed Houses</u>

The estimated payback period (PBP) for newly constructed houses is given as (Chel and Tiwari, 2011):

The system PBP = (system total annual cost per house at certain discount rate * system lifespan in years) / current annual cost of electricity per house

Where: system annual cost at 0% discount rate is 1,007.7 KD, system lifespan is 20 years and current annual cost of electricity per house is 2,868 KD/house/yr.

PBP at 0% discount rate = $\frac{\mathbf{1{,}007.7KD \times 20}}{\mathbf{2{,}868KD}}$ = 7 years

PBP at several discount rates is given in Figure (4). It is shown that at 6.7% discount rate the PBP is 14.8 years, and at the break-even discount rate of 10.36% it is 20 years.

Figure 4: PBP of PV System for Newly Built Houses

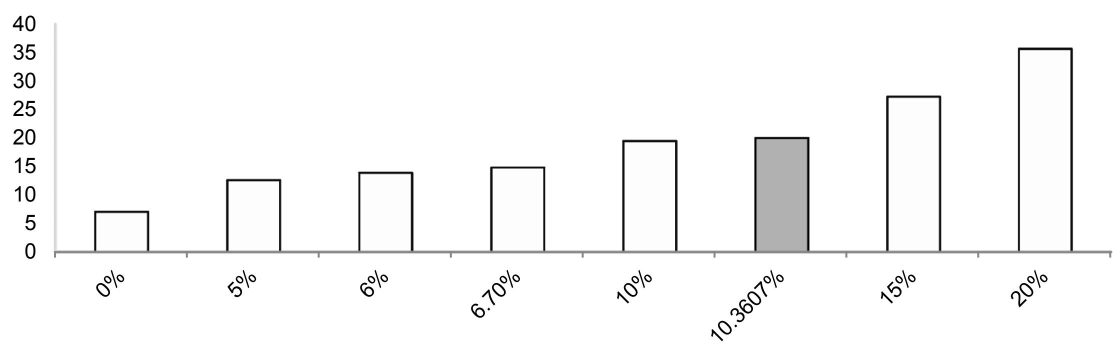

Figure 4 shows the estimated payback period of the PV at assumed discounted rates.

<u>PV System for Previously Built Houses</u>

The only difference between performing a BIPV system on a newly built and a previously built house is the cost of the BOS unit. The infrastructure of previously built houses does not adapt the PV system directly. Some adaptations are needed to the main utility box and installing new wiring conduits, to cover all extra costs. The estimated BOS initial cost of the previously built house is estimated to be 15% more than the BOS cost of a new house. The same method used for estimating the cost for newly built houses is used. The net cost/kWh is calculated for several discount rates. The results showed the net cost is 12.5 and 24.6 KF/kWh for 0.0% and 6% discount rates respectively. The results also revealed that with a 6.7% discount rate, annual saving for a previously built house is KD 653. The PV is economically probable when the discount rate is less than or equal to the break-even point of 9.82% discount rate. The payback periods are 7.4 and 15.5 years at 0% and 6.7% respectively.

CONCLUSIONS

Because of the extensive use of conventional power plants, Kuwait is considered one of the highest carbon dioxide emitters for each person in the world at 30.2 ton/person a year. A PV system would reduce the country's emissions by almost twenty three million tons each year. The sunny climate of Kuwait creates excellent conditions for increasing the peak hour power of the PV system, which in turn lowers the cost of the BIPV.

Considering the financial savings of the CO_2 decline resulting from using the new PV system, the EAC of the BIPV is lower than the EAC of the current conventional source of energy. At a 6.7% discount rate, the estimated cost/kWh of the BIPV for a new house is 25.2 KF, while for a previously built house it is 26.3 KF. The current conventional electricity cost is 34 KF/kWh. The annual savings, therefore, of BIPV for newly and previously built houses are 744 and 635 KD/house respectively.

The estimated payback periods of the BIPV, with 6.7% discount rate, for newly and previously built houses are 14.8 and 15.4 years respectively; at a 0.0% rate, they are 7 and 7.4 years respectively. These are shorter than the twenty-year lifespan of the BIPV. BIPV solar energy is economically and technically feasible in Kuwait when the discount rate is equal to, or less than, the break-even point of 10.36% for new houses and 9.82% for existing houses.

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BIOGRAPHY

Mohamed A. Hadi can be contacted at Tech Departmetn of the Council of Ministers, Kuwait, email: db-bwok@csc.net.kw

Professor Refaat H. Abdel-Razek can be contacted at Arabian Gulf University, Bahrain, email: refaathar@agu.edu.bh

Walid M. Chakroun can be contacted at Kuwait University, Kuwait, email: chakroun@kuc01.kuniv.edu.kw