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RESEARCH ARTICLE

COMPARISON ON THE USE OF SILICON AND FLEXIBLE ORGANIC SOLAR CELLS AS REPLACEMENTS FOR FOSSIL FUEL ENERGY SOURCE OF ELECTRICITY IN THE UK AND KURDISTAN, IRAQ

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ABSTRACT

The majority of businesses use electricity derived from non-renewable fossil fuels. These will run out and are causing substantial environmental damage threatening the future generations. Previously, we considered the energy utilization in a small business. If SME's could use solar energy then crucially damage to the environment can be prevented. Solar cells involve harnessing the energy from the sun to generate electricity. In this study a comparison of the use of silicon solar cells to flexible organic photovoltaic solar cells (OPV) is made considering the electricity energy requirements of a model micro-business business in the UK and Kurdistan, Iraq. The comparison shows it is more feasible to replace the existing non-renewable fossil fuel sources with flexible organic solar cells in Iraq due to greater solar radiation striking the earth's surface. Our research suggests that flexible solar cells can replace a significant amount of the energy requirements even in the UK and a much larger proportion in Kurdistan, Iraq. Using existing 20% efficient silicon solar cells we can replace 28% and 88% of the energy requirements of the microbusiness in UK and Kurdistan, Iraq respectively. However, with 20% efficient flexible organic solar cells placed on windows then this can replace 78% and 235% of the energy requirements in the UK and Kurdistan, Iraq respectively due to the larger areas being available.

INTRODUCTION

Currently, the vast majority of businesses use energy derived from non-renewable fossil fuel sources. The major problems with this resource are that it will run out eventually and causes major environmental problems associated with climate change (Barrett, 1997; Carraro and Siniscalco, 1993 and Outlook, 2010). Environmental problems arise due to rapidly increasing demand from population growth, increased lifespan, global warming causing ice caps to melt, rising sea levels, flooding and depletion of the ozone layer. Numerous studies are available focusing on large distributors, manufacturing companies and domestic users (Hattori *et al*., 2005). However, there have been much fewer studies (Kannan and Boie, 2002) focusing on SMEs in the service sector. There are a large number of SMEs in UK and Iraq and their combined impact is highly significant. Previously, a small service business, a hair salon has been analyzed in terms of its energy utilization and CO_2 generation (Azabany *et al*., 2014). The feasibility of replacing fossil fuels sources of electricity with solar energy from the sun has been investigated and a comparison was made between UK and Iraq using silicon solar cells commonly available with an efficiency of 20%. In this paper, the energy analysis for the micro-business in the UK, which could be duplicated in Kurdistan, Iraq is taken from our previous work and further analysis is carried out using the different types of available solar cells. A comparison has been made between using existing silicon solar cells commonly available with an efficiency of 20% with flexible organic solar cells fabricated in the research laboratories with an efficiency of 5 % and projected efficiency of 20%.

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Background

In order to meet the demand for renewable energy, the photovoltaic sector has experienced exponential growth over the last few years. Back in 2004, 90% of this emerging market was dominated by wafer-based crystalline silicon technology (Ja¨ger-Waldau, 2005). New technologies are being developed and forecast to enter the market in the near future. One of these promising alternative concepts is organic solar cells. Though still lacking behind in conversion efficiency, they exhibit several advantages over established technologies. Among these are the potential of cheap processing on large areas, possible semi-transparency, mechanical flexibility and light weight. In conventional solar panels, the supporting structures of the panel like glass, brackets etc. are mostly twice as costly as the photovoltaic materials manufactured on them. As paper costs approximately a thousandth of glass, solar cells using printing processes can be much cheaper than conventional solar panels. Also other methods involving coating papers with materials include first coating the paper with a smooth material to counter-act the molecular scale roughness of paper. But in this method, the photovoltaic material can be coated directly onto untreated paper. Traditional inorganic Si-PVs are able to convert 25% of sun energy to electricity (Green *et al*., 2011) with an average life span of twenty years, but are associated with high cost and complicated manufacturing processes. Currently, Si-PVs account for 13% of market share in the global renewable energy sector, and 3% of the total global energy generation sector (Sawin *et al*., 2011).

On the other hand, thin film PVs such as OPVs are only able to convert 8% of sun energy to electricity (Green *et al*., 2011), and have a maximum life span of approximately one year even with encapsulation. Regardless, it has been reported that OPVs have the potential to convert up to 17% of sun energy and can be fabricated by low cost roll-to-roll manufacturing methods using significantly reduced amount of raw materials (Park *et al*., 2009). This reduction in material usage not only results in more economical manufacturing, but also creates less environmental impact. This compatibility with roll-to-roll manufacturing has resulted in the development of a number of thin film PV technologies that aim at high profitability and low cost manufacturing. Currently, the initial cost of investment for traditional Si-PVs is around $3.20/W (http://www. solarbuzz.com/facts-and figures/ retail-price-environment/ module-prices), and that of OPVs is only around $2.50/W], which enables higher cost competitiveness against conventional technology. Figure 1 and 2 show what typical flexible organic solar cells look like.

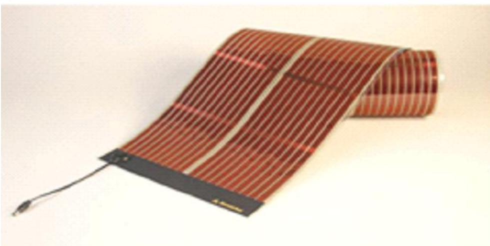

Figure 1. Flexible organic solar cell

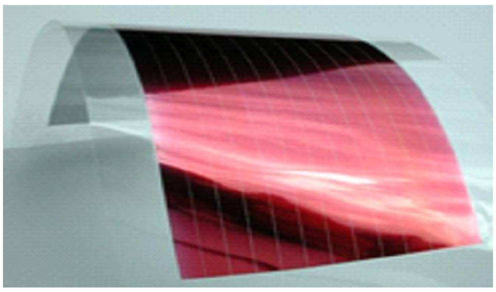

Figure 2. Transparent organic solar cells

RESULTS AND DISCUSSION

Energy consumed and costs: For the micro-model business considered, the energy consumed and the number of days the business was open are shown in table 1 (Azabany *et al*., 2014).

Table 1. Monthly energy utilization, customers and days open

Month	No of days open	Units consumed (kWh)
Jan	25	331
Feb	25	379
Mar	27	442
April	24	325
May	27	367
June	26	404
July	26	455
Aug	26	410
Sept	24	402
Oct	27	414
Nov	27	525
Dec	23	568
Total	307	5,022

The efficiency of solar cells has been increasing as new materials and architectures have been developed. A major objective of this project is to examine the feasibility of replacing electricity generated from non-renewable fossil fuels with different available solar cells. A number of factors effect how much electricity is generated from silicon solar panels on the roof and the use of flexible organic solar cells. These include the size, number of panels, their power rating, position on the roof or available window space, and the hours of sunlight. Standard production solar panels based on silicon solar cells generate 1000W/m^2 with an efficiency of about 15-20%; hence a 1m^2 panel produces about 150-200W in good sunlight conditions and less in cloudy dull conditions. The efficiencies of commercial solar are expected to rise because research has already produced higher efficiency solar cells.

Relationship between energy consumption and CO_2 generated

To consider how much CO_2 can be prevented from getting into the atmosphere and its impact on the environment we can relate electricity generated to the equivalent CO_2 produced. It has been calculated that in the U.K 1KWh electricity generates an equivalent of 0.43kg of CO_2. Hence the amount of CO_2 that can be prevented from entering the atmosphere can be calculated (Johnson, 2002; Johnson and Keith, 2004 and Pandey *et al*., 2011).

$$1kWh\ of\ electricity = 0.43\ kg\ of\ CO_2$$

Hence, CO_2 released by micro-businesses onto the atmosphere/year can be calculated as

$$5022\ kWh = 0.43 \times 5022\ kg\ of\ CO_2$$
$$= 2159.46\ kg\ of\ CO_2$$

Comparison of the feasibility of replacing fossil fuels with existing silicon solar panels and flexible organic solar panels

Solar cells rely on sunlight for their mode of operation so we consider the average number of sunlight hours in both the UK and Kurdistan, Iraq see figure 1 (Azabany *et al*., ?).

U.K and Iraq, the average numbers of hours of sunlight per day in the U.K is around 4 hours but in Iraq it is around 10 hours which would indicate that Iraq is more conducive to the use of solar cell technology than the U.K.

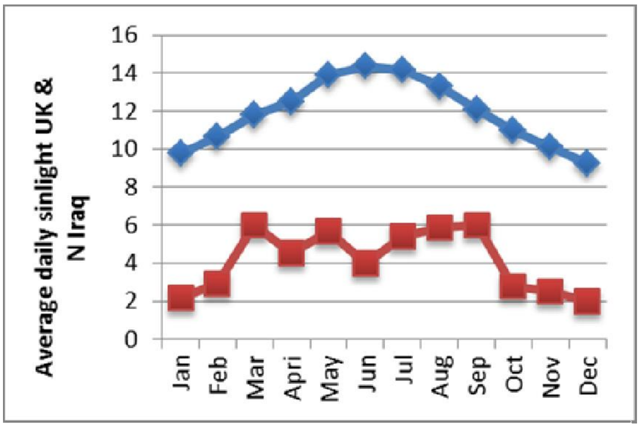

Figure 1. Shows a comparison between average daily sunshine in Kurdistan, Iraq compared to Manchester, UK in 2012

From the above figure we can see although the number of sunlight hours fluctuates during the whole year in both the The expected electricity generated in kWh per day using solar panels can be calculated using the following formula:

$$Electricity = A \times 1000 \times \xi \times t$$

A is the area of solar panels, ξ is the efficiency and t is the

hours of sunlight. Considering the micro-business hairdressing salon and we can calculate the amount of electricity that can be generated daily in UK and Iraq (Azabany *et al*., 2014). The physical dimensions of the roof are 6 x 2 = 12 m^2 and about 50% of it is available for installation of silicon solar cells. Hence, an area of $6m^2$ is this available for solar cell installation. The amount of electricity generated in a typical day UK is

Electricity (UK) = 6 x 1000 x 0.2 x 4 = 4,800 Wh/day = 4.8 kWh/day

For Kurdistan, Iraq the calculation involves longer hours of daily sunlight and the intensity of sun is also much higher hence repeating the calculation gives

Electricity (N. Iraq) = 6 x 1000 x 0.2 x 12 = 14,400 Wh/day = 14.4 kWh/day

As mentioned earlier the trend in solar cell technology is towards increased efficiency and more versatile organic solar cells, which can be applied to windows readily in the form of transparent thin films (Liu *et al*., 2011). Applying these solar cells to windows of Gents Groom Hairdressing Salon and assuming that the efficiency will rise to 20% from an existing value of about 5% the proposition for solar cells as a viable alternative to fossil fuels is increasingly more attractive. Application of flexible solar cells to windows can provide additional electricity. The windows on the Gents Groom Hair Salon measure 2.1 x 3.8 = 7.98 m^2, which is approximately 8 m^2 and therefore two windows give an area of 16 m^2. Therefore, the amount of electricity that could be generated with 5% efficient organic solar cells can be calculated

Electricity (UK) = 16 x 1000 x 0.05 x 4 = 3,200 Wh/day = 3.2 kWh/day

Electricity (N. Iraq) = 16 x 1000 x 0.05 x 12 = 9,600 Wh/day = 9.6 kWh/day.

If organic solar efficiencies increased to 20% comparable to existing silicon solar cells then these figures increase to 12.8 kWh and 38.4 kWh for UK and Kurdistan, Iraq respectively. Hence, in Kurdistan, Iraq 3 times more electricity can be generated per day using flexible organic solar cells. Based on UK figures (0.43 kg/kWh) we can calculated amount of CO_2 reduction if a switch was made from non-renewable fossil fuels to flexible organic solar cells. For Kurdistan, Iraq we used the Taiwan figure (0.73 kg/kWh) because the weather conditions are similar in the two countries. A comparison can be made of the use of silicon solar cells to organic solar cells with 5% and 20% efficiencies. Also, the corresponding reductions in harmful carbon dioxide emissions can be calculated as shown in table 2 below.

Table 2. Comparison between Manchester, UK and Kurdistan, Iraq for Silicon solar cells and 5% and 20% efficient organic solar cells and amount of reduction in CO_2

Silicon Solar cell efficiency (%)	Organic Solar cell efficiency (%)	UK (kWh)	N. Iraq (kWh)
	5	3.2	9.6
	20	12.8	38.4
20		4.8	14.4
		Annual (307 days)	
	5	982	2,947
	20	3,930	11,789
20		1474	4421
		Annual CO_2 reduction (kg)	
	5	422	2,151
	20	1,690	8,606
20		634	3227

Clearly calculations for the replacement of fossil fuels with solar cells show that the carbon emission will be decreased and reduce damage to the atmosphere. The benefits in Iraq would be much greater due to more sunlight and about 5 times the reduction in CO_2 emissions can be achieved in Kurdistan, Iraq compared to UK. This is also applicable to other countries in the Middle East. For the UK we calculate the percentage of electricity generated from 20% efficient solar cells compared to fossil fuels to be as follows:

$$\%E(replaced) = \frac{E(solar)}{E(fossil)} \times 100$$

$$= \frac{1474}{5022} \times 100 = 29\%$$

However, for the same business in Kurdistan, Iraq with 20% efficient silicon solar cells and longer day light hours we can calculate the percentage of electricity needs that can be replaced with solar cells.

The calculations above using the solar panel with efficiency of 20% can replace only 29% of the total electricity required to run Groom Gents Hairdressing salon in the U.K. The replacement of fossil fuels with solar cells will also reduce the carbon emission into the atmosphere and reduce damage to the environment. However, in Kurdistan, Iraq due to longer daily and annual daylight hours we can replace 88% of the energy needs with silicon solar cells.

Table 3. Comparison of the percentage of current electricity requirements that can be replaced with solar with silicon solar cells and flexible organic solar cells

Solar cell type	Percentage of the energy requirements replaced with solar in the UK	Percentage of the energy requirements replaced with solar in Kurdistan, Iraq
Silicon solar cells (20%)	29	88
Flexible organic solar cells		
5%	20	59
20% (theoretical)	78	235

Existing flexible organic solar cells can replace 20% and 59% in the UK and Kurdistan, Iraq respectively. With accelerating developments in nanotechnologies and materials the efficiency is expected to increase rapidly to 20% and beyond in the next few years. When the efficiency reaches 20% then we can replace 78% and 235% in the UK and Kurdistan, Iraq. In the summer Kurdistan, Iraq has a requirement for cooling and the electricity for the cooling systems can be derived from surplus solar source of energy. Hence, there will be no detriment to the environment and no need to use fossil fuel sources of electricity to run this small business. In addition, these result in 1,690kg and 8,606 kg decrease in the CO_2 emissions from this small business alone. The approach and methodology employed in this analysis can be used with other microbusinesses and with millions of microbusinesses operating there will be a major reduction in carbon emission if all the businesses could employ solar energy for their daily energy needs.

Conclusions

A methodology to compare a micro-business in the UK and Kurdistan, Iraq for energy utilization has been proposed. A large proportion of fossil fuel sources can be replaced with flexible organic solar cells. Flexible solar cells can replace a significant amount of the energy requirements. For existing silicon solar cells we can replace 29% and 89% of the energy requirements of the microbusiness in the UK and Kurdistan, Iraq respectively. However, with flexible organic solar cells placed on windows projected 20% efficient solar cells will be able to replace 78% and 235% of the energy requirements in the UK and Kurdistan, Iraq respectively due to their flexibility and larger areas where they can be utilized. The importance of the use of flexible organic solar cells are that with lower costs and larger areas been utilized this technology can be readily implemented in places such as Kurdistan, Iraq. This study shows that with increasing new technology and greater efficiencies being made with solar cells, the opportunities to utilize these will provide benefit both to society as well as the environment.

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