Study Of Solar Charging Facility For Electric Vehicles In Edinburgh

Walid Nassar, Yasser Shaban

Abstract: The solar power system decreases carbon dioxide (CO2) emissions which are the lead cause of global warming. This paper presented a novel way to design a commercial solar photovoltaic (PV) farm to provide electricity for 10% of the Edinburgh domestic car fleet. The design is used for sizing of the solar system based on an excel spreadsheets. The results show that the proposed solar system reduces the CO2 emissions with around 95% less than the conventional energy system. Around 0.5TWh of electrical energy is required to meet Edinburgh domestic car fleet whenever converted to electrical vehicles. The PV solar panels at the investigated site has a capacity factor of around 12%. The dynamic tilt angle is estimated for the investigated site while the fixed tilt angle is determined to be 49°. Depending on dynamic solar panels leads to harvesting more solar energy than depending on fixed tilt angle, around 14% higher energy. The meter square of land in Edinburgh receive some 950KWh per year based on the dynamic tilt angle. Around 218,000 of solar panels are required to meet 10% of Edinburgh domestic car fleet.

Index Terms: CO_2 cut down, stainable technology, solar charging facility, solar photovoltaic system design.

1 INTRODUCTION

The world experiences a huge crisis with conventional energy sources either for production from sustainable sources or in eliminating its impacts such as greenhouse gasses or air pollution. Air pollution leads to 29 thousand deaths a year in the UK. Nitrogen dioxide alone which found in diesel fumes responsible for 23,000 of deaths a year [1]. In the USA, cars and trucks account for one-fifth of all USA emissions. Burning one gallon of gas emits around 24 pounds of Carbon monoxide (CO) and other global warming gasses [2]. Modern cars release reasonable amounts of pollutants if kept in good condition, but the problem with large number of old cars on roads which emit a great amount of emissions [3]. Car pollution has different impacts on the environment. It deteriorates the air quality by releasing detrimental gasses and particles like Carbon monoxide, Oxides of nitrogen (NOX), Fine particles and hydrocarbons. All of these gasses have a damaging impact on people's health, animals and vegetation locally. In addition, fossil fuel cars contribute to high noise in cities due to engine's sound [4]. Many countries depend on fossil fuels as the main source of energy and electricity, roughly 80% of total primary energy supply comes from fossil fuels [5]. 60% of electricity production in OECD (Organization for Economic Cooperation and Development) comes from burning coal, gas and oil [6]. Although CO2 and other emissions come from cars dwarfs that come from power plants, it is highly appreciable to produce electricity from renewable energy plants instead of fossil fuel plants. The problem of conventional sources of fuels is not related to its emissions only but it is relevant to the shortage of these sources that not last long and this definitely contributes to achieving environmental balance and promote the sustainability.

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The recorded studies tackled optimization of solar PV systems from the different point of views. Design a solar PV system accurately requires considering all factors which effect on the PV panel output, such as ambient temperature, tilt angle, coordinates of the site, global and diffuse irradiation which strikes the tilted panels. Ignoring any of these parameters leads to inaccurate results, for example, Rahul Khatri [7] designed a solar PV system to meet the load demand of a hostel at MNIT University. Khatri considered important assessment factors such as the financial calculations and environmental impact of the project. However, the study ignored the influence of the ambient temperature and the tilt angle of the panel output. In addition, the yearly average irradiation which used in the calculation is not clear if it is global, diffuse or slope irradiation. Senol et al. [8] proposed an optimization technique for investors and technical staff for designing a large-scale PV power plant with a focus on self-consumption policy. The authors used an iterative approach for the optimum capacity of the system with considering the payback period as the decision criterion. In contrast with the previous study, Senol et al. took into account almost all parameters related to optimisation process of a large-scale PV plant. Tilt angle, orientation of modules and type of the mounting system are considered as primary input parameters. The authors considered available area at an early stage of the design as a key factor in estimating the farm size. The ambient and the cell temperature are taken into account for the estimation of the panel output. This study tackled the optimization of the solar system from different point of view. The design of the system is done based on dynamic tilt angle which expected to harvest higher energy. The detailed economic study is considered as well for this study, in addition the environmental impact of the system. The calculations in this report based mainly on Excel spreadsheets which published with the book windows in building [9]. The author developed a new technique to estimate the best dynamic tilt angle for each month. The rest of the paper is organized as follows: second section describes the data used through this paper. Third section presents the methodology of the study. Fourth section shows results and the discussion. Then the study of the environmental impact and the financial matters of the system are presented in the fifth section.

2 Description of the data

Design a solar farm to supply the Electric Vehicle (EV) under study requires estimating the electricity consumption of one car to determine the whole load demand. Weather data of the site under investigation such as solar irradiation and temperature data are required as well.

2.1 Estimation of the Energy Demand

The consumption of electrical car varies from city to another based on the geography of the land, and so, it is required to estimate the consumption of EV in the city under study. An experimental study is done in Edinburgh by a team of researchers form Edinburgh Napier University and Edinburgh University for studying the performance of EV. It shows that the energy consumed per Km by EV is 0.164KWh [10]. Now, to estimate the load demand which required to be covered by the solar farm, it is necessary to know the number of Edinburgh car fleet. The number of cars is determined based on the city's population which is 486,120 [11], the average household size which is 2.38 [12], and the number of cars per household which equals 1.13 [13]. Based on the previous data, the Edinburgh domestic car fleet is determined to be 230805 cars. While the annul mileage of 4-wheeled cars in Great Britain equals 8200 miles per car [13], then the annual energy demand of one car in Edinburgh equals 2,164KWh. As a result, the annual energy demand of 10% of cars in Edinburgh equals 50GWh which is the required load demand under this study.

2.2 The Solar Data

The city under study locate at 55.9 N and 3.2 W. There are different sources to get the solar irradiation data. NASA website is one of these sources which presents average monthly horizontal irradiation for all sites all over the world based on the latitude and longitude of the site. While the data in this study is published in the book Windows in Building [9] as an average monthly horizontal irradiation data as table 1 shows.

Table 1

Horizontal global and diffuse irradiation.

Global Irrad.	Jan	Feb	Mar	April	May	June
	0.43	1.0	1.82	3.21	4.1	4.5
	July	Aug	Sep	Oct	Nov	Dec
	4.09	3.34	2.35	1.3	0.57	0.33
Diffuse Irrad.	Jan	Feb	Mar	April	May	June
	0.29	0.62	1.11	1.76	2.25	2.48
	July	Aug	Sep	Oct	Nov	Dec
	2.34	1.93	1.35	0.78	0.37	0.23

2.3 Temperature data

The PV module efficiency is highly sensitive for ambient temperature as the efficiency decrease with increasing the temperature. So, for accurate design of the solar farm temperature must be taken into account. The source of the data for this study is the Met Office, an experimental government department in UK, which offers most up to date temperature data since 1910 [14]. Table 2 shows the monthly maximum and minimum average temperature. Table 3 presents the different variation percentages for the temperature through the whole day. The data in table 3 is used for converting temperature data in table 2 to hourly temperature data as will be discussed later.

Table 2

Monthly average temperature during 2015 [14]

Max. temperature	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**
	5.2	5.7	7.6	10.9	11.2	14.4
	July	Aug	Sep	Oct	Nov	Dec
	14.4	15.8	16.6	14.6	12.4	8.9
Min. temperature	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**
	-0.1	0.1	1.1	1.7	4	6.9
	July	Aug	Sep	Oct	Nov	Dec
	8.7	9.3	7	5.1	3.6	0.4

Table 3

Diurnal temperature swing [15]

Hour	Z %	Hour	Z %	Hour	Z %
1	87	9	71	17	10
2	92	10	56	18	21
3	96	11	39	19	34
4	99	12	23	20	47
5	100	13	11	21	58
6	98	14	3	22	68
7	93	15	0	23	76
8	84	16	3	24	82

2.4 PV panel data sheet

Module datasheet is important for estimation of cell temperature and the PV module output as the study shows later, so determining the module type should be at early stage of the design. For this study, polycrystalline module belongs to LDK Company is opted [16]. Model LDK-230P-20 is used as a practical choice which is installed in the solar farm of Edinburgh University.

2.5 Inverter Data sheet

Inverters work as interfacing equipment between the PV modules and the grid for two reasons. One is to ensure that the PV modules operate at the maximum power point (MPP). To inject AC current into the grid is the other reason [17]. Choosing the optimal inverter is very important matter because the under-sizing of inverter will cut-off the output of the solar panels regardless how big it is and also lead to overheating the electronic components that make the inverter life span is shorter. On the other hand, over-sizing the inverter is the optimal choice for all designers to avoid the drawbacks mentioned above in case of under-sizing and it make it possible to add further panels to the existing installations [18]. For the purpose of this study, an inverter from SMA Company, model Sunny Central 1000CP XT, is used [19].

3 Methodology

3.1 Design of a PV solar farm

To define the number of modules in a solar farm, Solar output energy of one module should be estimated. Various parameters should be considered to determine the output of a solar module such as (1) rotation of earth, i.e. the daily rotation of the Earth about its axe and the seasonally rotation of it around the Sun, (2) site of modules, i.e.

Longitude and latitude, (3) slope of modules or tilt angle and azimuth angle, (4) ambient temperature. (5) Shading [20]. Fig. 1 below shows a flowchart which simplifies and clarifies the required steps to estimate the output energy of one module using horizontal global and diffuse irradiation in table 1, number of modules, array size, number of inverter and number of farms. It is worth mentioning that all calculation will be done based on the day 16 of every month. To design a solar farm, certain steps are required as follows:

Step 1
Convert the monthly average solar data in table 1 to hourly solar irradiation data. Some software program, called calc04-09, which has been issued with the book windows in building is used to perform this [9].

Step 2
One of the important parameters that effects on the modules performance is tilt angle, i.e. the slope of the modules with the horizontal. A software program, code is attached in the appendix, is prepared by the author to estimate the optimum dynamic tilt angle based on “calc04-10” spreadsheet which published with “Windows in Building” book.

Step 3
Depending on the data will be estimated in step 1 and 2, the slope irradiation would be calculated using another software, called calc04-10, which has been issued with the same book of windows in building [9].

Step 4
The hourly average temperature is estimated based on equation 1. Then, cell temperature using equation 2 is estimated [15].

Th = Tmax – Z (Tmax – Tmin) (1)

Equation 1 gives the hourly ambient temperature, Th, based on the maximum and minimum monthly averaged temperature, Tmax, Tmin, respectively as presented in table 2, and the diurnal temperature swing as given in table 3.

Equation 2 is used for the estimation of the cell temperature which is used in the next step to calculate the module output [21].

$$Tc = Ta + \frac{Gslope}{Gnoct}(Tc,noct - Ta,noct)\left(1 - \frac{\eta stc}{\tau\alpha}\right) \quad (2)$$

Where:
Ta, air / Ambient Temperature
$Gslope$, the global slope irradiation
$Gnoct$, equal to 800W/m2
Tc,, cell Temp at NOCT
Ta, air temperatures at NOCT
ηstc, cell efficiency at STC
$\tau\alpha$, absorptivity of the Module, 0.8

Step 5
Equation 3 is used to estimate the module output power based on the two main parameters: slope irradiation and cell temperature [22].

$$P = \eta_{mod}\ x\ A\ x\ G_{tit}\ x\ [1 - 0.0045(T_C - 25)] \quad (3)$$

Where
η_{mod}, electrical efficiency at STC
A, Panel service area
G_{tit}, slope irradiation
T_C, cell temperature

Step 6
After the estimation of the annually output energy of one PV module in Edinburgh, the total number of modules could be estimated depending on the energy demand which is calculated before. Then, based on the inverter capacity the array size or substation size could be determined. The PV array include series connected modules called string and these strings connected in parallel to supply much more current. The number of modules connected in series is opted after estimation of minimum and maximum Open-circuit voltage of the module from equations 4 and 5 respectively [23].

$$VDCminMOD = Vmpp\left(1 + \frac{TDCUocMOD\ X\ \Delta Tmax}{100\%}\right) \quad (4)$$

Where:
$Vmpp$, PV module voltage at maximum power point = 29.3, from solar module datasheet.
$TDCUocMOD$, temperature voltage coefficient = -0.33 %/°C, from solar module datasheet.
$\Delta Tmax$, temperature difference between STC temperature and maximum expected module temperature (T_{maxMOD}).

$$VDCmaxMOD = Voc\left(1 + \frac{TDCUocMOD\ x\ \Delta Tlow}{100\%}\right) \quad (5)$$

Where:
Voc, Module open circuit voltage = 36.9 V, from solar module datasheet
$TDCUocMOD$, temperature voltage coefficient = -0.33 %/°C, from solar module datasheet
$\Delta Tlow$, temperature difference between STC temperature and minimum expected ambient temperature, $\Delta Tlow$.

Similarly, the number of strings per array, i.e. parallel connected modules, could be estimated by determining the maximum output current per module from equation 6 below [23].

$$IDCmaxStr = Isc\left(1 + \frac{TDCIocMOD\ x\ \Delta Tmax}{100\%}\right) \quad (6)$$

Where:
Isc, short circuit current = 8.43 A, from solar module datasheet.
$TDCIocMOD$, temperature current coefficient = 0.06 %/°C, from solar module datasheet.
$\Delta Tmax$, temperature difference between STC temperature and maximum expected module temperature.

3.2 Estimation of the area of substation

By this, the number of modules, either connected in a series or parallel, per array is estimated. The next step is to estimate the area required for each substation. This area depends on the area of the module and number of modules, taking into account the optimal distance, d, between panel rows to avoid shadowing. This distance, d, can be estimated by equation 7 below [24].

$$d/a = cos\beta + sin\beta/tan\varepsilon \ (7)$$

$$\varepsilon = 90 - \delta - \Phi$$

Where a is the module width, β is tilt angle and ε is the sun's angle which can be expressed by ecliptic angle, δ, and the geographical latitude, Φ, as fig. 1 clears.

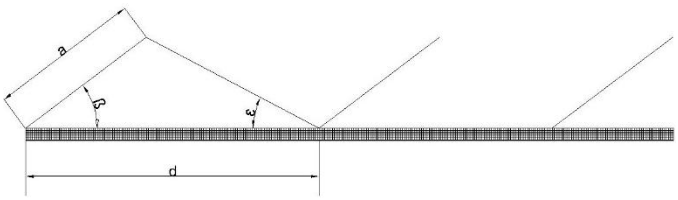

Fig. 1. *Optimal distance between rows of modules arrangement [23].*

4 Results and Discussion

4.1 Estimation of the Hourly Horizontal Irradiation

The hourly global and diffuse irradiation on a horizontal surface is estimated using calc04-09 software as illustrated in step1 of the previous section [9]. Table 4 and table 5 shows hourly global and diffuse irradiation respectively.

Table 4

Hourly global horizontal irradiation.

M	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	22	78	115	96	47	0	0	0	0
7	3	0	10	87	150	186	163	110	40	0	0	0
8	16	9	66	164	230	261	235	181	105	30	0	0
9	31	58	130	243	310	335	306	253	174	85	23	2
10	45	108	191	315	381	399	369	318	240	140	61	32
11	56	149	239	370	434	447	415	367	290	184	92	58
12	62	173	266	400	463	473	440	393	318	208	110	73
13	62	173	266	400	463	473	440	393	318	208	110	73
14	56	149	239	370	434	447	415	367	290	184	92	58
15	45	108	191	315	381	399	369	318	240	140	61	32
16	31	58	130	243	310	335	306	253	174	85	23	2
17	16	9	66	164	230	261	235	181	105	30	0	0
18	3	0	10	87	150	186	163	110	40	0	0	0
19	0	0	0	22	78	115	96	47	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

Table 5

Hourly diffuse horizontal irradiation.

M	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	17	53	74	66	36	0	0	0	0
7	5	0	9	60	95	113	104	76	31	0	0	0
8	14	8	50	102	136	150	141	115	72	24	0	0
9	23	42	88	139	172	183	175	150	108	58	18	2
10	30	70	118	170	201	210	202	178	137	86	42	24
11	35	90	140	191	222	229	221	199	158	106	59	40
12	38	100	151	202	233	239	231	209	169	117	67	48
13	38	100	151	202	233	239	231	209	169	117	67	48
14	35	90	140	191	222	229	221	199	158	106	59	40
15	30	70	118	170	201	210	202	178	137	86	42	24
16	23	42	88	139	172	183	175	150	108	58	18	2
17	14	8	50	102	136	150	141	115	72	24	0	0
18	5	0	9	60	95	113	104	76	31	0	0	0
19	0	0	0	17	53	74	66	36	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0

4.2 Estimation of the tilt angle

The tilt angle could be used as same as the angle of latitude referring to the solar electricity book [25]. However, for higher slope irradiation, a visual basic code is developed by the author based on "calc04-10" spreadsheet to calculate the monthly optimal tilt angle. The objective of this subroutine program is estimation of the slope irradiation for every month at different tilt angle from 0 to 90˚. The tilt angle at which the highest irradiation occurred is then recorded. The findings show that the optimal tilt angle is varying all over the year from season to another as shown in table 6.

Table 6
Dynamic and fixed tilt angle at Edinburgh

Optimal Tilt Angle based on Day 16th	Jan	Feb	Mar	April	May	June
	70	60	50	40	30	30
	July	Aug	Sep	Oct	Nov	Dec
	30	30	40	60	70	80

4.3 Estimation of the Slope Irradiation

As mentioned earlier, the software "Thesis_calc04-10" is used to estimate the hourly slope irradiation based on hourly global and diffuse irradiation, in addition to the tilt angle for each month. It is worth mention that estimation of the slope irradiation is performed based on the day 16th. To show the influence of using fixed or dynamic tilt angle on the harvested solar energy, the slope irradiation is estimated in both cases. With a fixed tilt angle one module is expected to produce around 815 KWh/m^{2} / year, while more than 950 KWh/ m^{2} / year will be harvested from the same module with the dynamic tilt angle. That is mean about 14% higher solar energy would be harvested with using tracking system than fixed panel system. Fig. 2 shows the monthly harvested solar energy in the two cases.

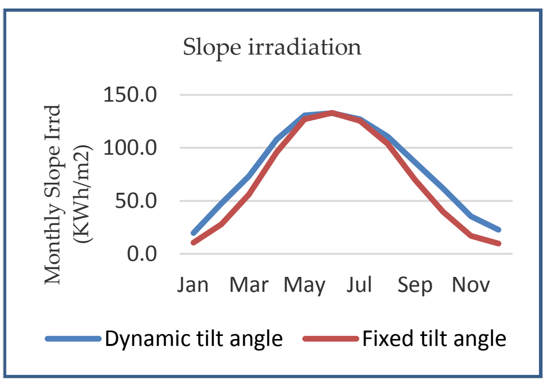

Fig. 2. *Slope Irradiation with tracking and fixed system.*

4.4 Estimation of the Output Energy of the Panel

Once slope irradiation is determined, it is possible to determine the potential module output taken into account the efficiency of the module at different ambient temperature. Due to the negative impact of the high ambient temperature on the module output, hourly ambient temperature and then hourly cell temperature must be considered to accurately evaluate the potential output energy of a module at Edinburgh. The module datasheet parameters are required for the estimation of the module output energy.

4.4.1 Estimation of the Hourly Ambient Temperature

The potential hourly ambient temperature for each month could be estimated using equation 1. As per equation 1, maximum and minimum ambient temperatures are required as already presented in table 2. Based on the data in table 2 and table 3 and using the equation 1, the hourly ambient temperature is estimated.

4.4.2 Estimation of the Cell Temperature

Cell temperature term refers to the temperature of the surface of the PV module. The cell temperature is the same as ambient temperature by night, but it could reach 30˚C or more than the ambient temperature at full sun [26]. A part of the absorbed solar energy by the module is converted into thermal energy which is dissipated by conduction, radiation and convection. The cell temperature is highly sensitive for the ambient temperature and the operation of the panel, so the operating temperature plays a vital role in the module performance [27]. The expected hourly cell temperature in this study is estimate using equation 2 as presented before.

4.4.3 Estimation of the PV panel output

Solar cell is the heart of the module; however, it cannot work alone without being included in a panel with other cells. The panels have a number of connected cells in series to produce a reasonable voltage and power where a single cell have a very low power and voltage. As illustrated earlier that the module output energy could be estimated using equation 3. The yearly output solar energy produced by the selected panel in this study is found to be around 250KWh/year.

4.5 Estimation of the size of PV substation

The output of one module definitely could not meet the full demand. More and more modules are required to be connected together to supply the huge load demand. Using the equations 4, 5 and 6, the size of PV array is summarized as shown in table 7 below.

Table 7
Size and specification of the PV substation

Number of panels connected in series in one string	25
Number of strings connected in parallel in one array	190
Number of Panels in one PV substation	4837
The distance between strings	2.7m
Number of inverters	45
The area of substation	21539 m2
Number of substation in the project	45
Total number of panels	4837*45= 217665

4.6 Capacity factor of a solar panel in Edinburgh

Capacity factor is a good measure for the energy generation. It is the ratio of the energy produced to the theoretical energy generated in case of the solar module work at the rated power at all times [28].

$$Capcity\ factor = \frac{\text{Energy Produced}}{\text{Theoretical energy generated}}$$

$$Capcity\ factor = \frac{250.3\ x\ 1000\ \text{Wh}}{235\text{W} * 365 * 24}$$

$$Capcity\ factor = 12.2\ \%$$

5 The Environmental impact

Despite the progression in renewable sources, the highest share of electricity production is still from fossil fuel as shown in fig. 3. Roughly 60% of electricity production in OECD (Organization for Economic Cooperation and Development) comes from burning coal and gas with a small contribution from the oil [6]. So, any step towards using renewable energies is highly appreciable towards decreasing carbon footprint. Solar energy is one of better choices as a fully green energy, just it fabricated and begin to produce electricity.

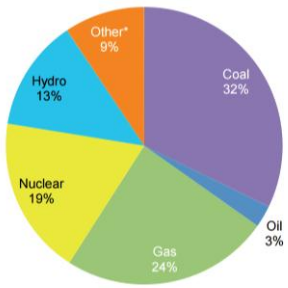

Fig. 3. *Sources electricity production in OECD (IEA, 2015)*

On the other hand, two thirds of Scotland's total emissions are coming from road transport [10]. This is the second huge benefit from this project which is converting 10% of Edinburgh's conventional cars to electrical vehicles which will be supplied from a solar farm and by this it reduces the carbon emissions and maintain sustainability which is the main purpose of this project. To tackle the matter of carbon footprint, a software program called Granta CES EDUPACK is used to estimate the environmental impact of creating this project considering Cradle-to-Gate' Life cycle evaluation. Then estimation of the reduced quantity of CO2 due to converting 10% of fuel engine cars to electric vehicles will be conducted.

TABLE 8

WEIGHTS OF VARIOUS COMPONENTS OF A SOLAR PANEL

Panel Components of one meter squared area	Weight (Kg)
One meter square of mono-cSi	0.725
Glass layer for protecting PV cells	3.6
Two Ethylene Vinyl Acetate to encapsulate the cells	0.19
Copper wire connected between all cells	0.13
Polyethylene for insulation	1.4
Polyester base and frame	7
Bakelite for electrical contacts	0.07

This software program is used to estimate the embedded energy and CO2 footprint for transporting and manufacturing of PV panels. The estimation is performed assuming only one square meter of Mono-cSi PV panel, as a functional unit, is fabricated and transferred from Jiangxi in China to Edinburgh in the UK over distance 20,338 Km by sea. The PV panel comprises from different layers as indicated in Table 8 above [29]. Fig. 4 and Table 9 show the carbon emissions and the embedded energy through different phases of the lifecycle of the PV panel beginning from material, manufacturing, transporting, use, disposal until end of life potential.

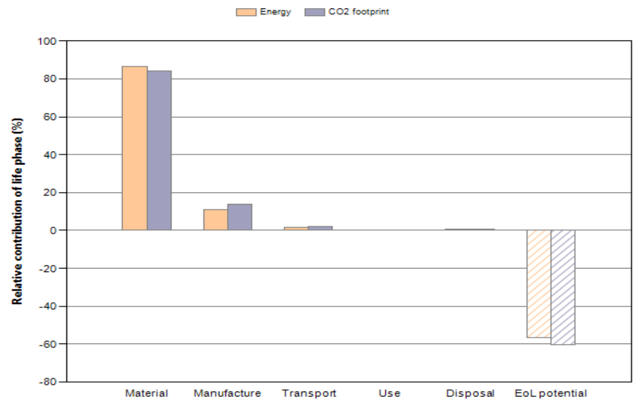

Fig. 4. *Energy and CO2 Impact of manufacturing 1m2 of PV panel*

TABLE 9

IMPACT OF CO_2 DUE TO MANUFACTURING $1m^2$ OF PV PANEL

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	1999.7	86.8	125.496	84.0
Manufacture	256.3	11.1	20.433	13.7
Transport	42.7	1.9	3.030	2.0
Use	0.0	0.0	0.000	0.0
Disposal	5.18	0.2	0.363	0.2
Total (for first life)	2303.9	100	149.322	100
End of life potential	-1303.2		-89.915	

Around 149Kg of carbon dioxide would be emitted due to using $1m^2$ of the selected module over its first life cycle (see table 9), in case of importing all modules from China as stated before. The whole environmental impact of the farm is illustrated as shown in table 10.

TABLE 10

THE ENVIRONMENTAL IMPACT OF THE SOLAR FARM

Carbon emitted from the Solar PV Farm	
Carbon emitted from using 1m2 of PV over 25 years	149.322kg
Total area of the panels = 217665*1.63	354794m2
Total Carbon released form the farm over 25 years	53Ktonnes
Carbon emitted from Conventional power plant	
Average quantity of carbon emitted from fossil fuels for electricity generation [30]	737.5g/KWh
Solar farm capacity per annum	56.5GWh/yr
Total carbon released if 56.5GWh will produced from Conventional sources for 25 years	1042Ktonnes
Carbon reduction from using the PV farm over 25 years	989Ktonnes

It is worth mentioning that fabricating these modules in countries depends on green electrical sources such as nuclear power will definitely declines a huge amount of the carbon emitted as in the case of France and Germany, in case of modules fabricated in any of them.

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6 Financial calculations

As per figure 5, there are two different costs that should be taken into account when considering the total cost of the solar farm. Firstly, the upfront costs, Capital Expenditure (CAPEX) or investment costs, which will be spent during the planning stage, purchasing materials and full installation of all components until commissioning. Secondly, the costs spent over the farm lifetime which known as operating and maintenance costs or Operating Expenditure (OPEX) and basically considered on an annual basis. There is a study on the cost reduction potential of large scale solar PV in UK published in November 2014. The study predicted that the CAPEX by 2016 would be £848 K/MWp and the OPEX over the project lifetime would be £607 K/MWp [31].

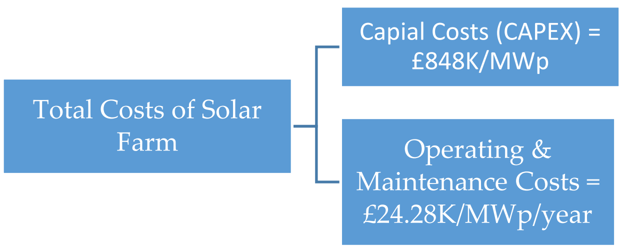

***Fig. 5.** Total costs of solar farm*

An excel spreadsheet has been prepared by the author to perform the financial calculations of the solar system. It is worth mentioning that the Feed in Tariff (FIT) generation and export payment rate for 1 July 2016 version is set to be 0.61p/KWh and 4.91p/KWh respectively [32]. Allowance of emitted CO2 is taken into account as an income for the project and it is found to £16.10 per tCO2.

6.1 Financial Calculations Summary

Table 11 shows the financial summary of the solar farm based on the calculations which was performed by the author in a separate excel spreadsheet as stated above.

Table 11

Summary of economic analysis of solar farms.

Inputs		
Module power capacity (W)	235	Datasheet
Total installed capacity (MW)	50	Estimated
Capacity factor (%)	12.2	Estimated
Energy generated from whole farms (MWh/yr)	54	Estimated
Capital expenditure (m£/MW) per unit power	0.848	By searching
Operating expenditure (£/MW/yr) per unit power	22,000	By searching
Total capital expenditure (£/54MW)	42,993,505	Estimated
Total operating expenditure (£/50MW/25yr)	27,884,950	Estimated
feed-in-tariff (pence/KWh)	0.61	
Export rate (pence/KWh)	4.91	
Assumptions		
Bank loan (40% from CAPEX) (£)	17,197,402	
Period of loan (years)	15	
Fixed rate (%)	6	
Inflation (%)	2	
Discount rate (%)	6.9	
Target rate of return (%)	9	
Feed-in-tariff duration (years)	25	
Output		
Annual loan repayment (£)	1,770,692	
Bank interest	9,362,978	
Annual cash outflow (£)	2,886,089	
Net present value over 25 years (£)	-23,524,957	
Payback period (years)	21	
Internal rate of return over 25 years (%)	2	

6.2 The Levelised Cost of Energy

The Levelised Cost of Energy (LCOE) is a good tool to compare between different energy technologies. It represents the costs of the system in terms of the project life time and it could be estimated from this equation below [33]:

$$\text{LCOE} = \frac{\text{Total costs over project lifetime(£)}}{\text{Energy produced over lifetime(MW)}}$$

$$\text{LCOE} = \frac{\text{CAPEX} + \text{OPEX} + \text{Bank interset}}{\text{Energy produced over lifetime(MW)}}$$

Total costs of the project include the CAPEX, OPEX and the bank interest over the project lifetime. By substituting these terms in the equation above, LCOE yields:

$$\text{LCOE} = \frac{42{,}993{,}505 + 27{,}884{,}950 + 9{,}362{,}978}{250 * 217665 * 25}$$

$$\text{LCOE} = \frac{80241433\ (£)}{250(\text{KWh/yr}) * 217665\ (\text{No. of panels}) * 25\ (\text{years})}$$

$$\text{LCOE} = 0.0589\ £/\text{KWh}$$

$$\text{LCOE} = 58.9\ £/\text{MWh}$$

Conclusion

This study presented a detailed design for a 50MWp PV grid connected power plant as a facility for charging electric vehicles in Edinburgh, Scotland. The introduction has shown that the huge amount of emissions is coming from energy production and Transport sectors. Due to this, people are suffering from severe health problems especially from the emissions of transportation where they are in a direct contact with it. So, attention should be taken towards reducing GHG from the world as a whole as reducing the carbon emissions in Europe and America will not solve the impact of emissions which comes from far continents like Africa or Asia. The harm definitely returns on the whole mankind. The report concludes the following:

- The average annual energy demand for supplying 10% of electric vehicles in Edinburgh is around 50GWh per annum.
- LDK-230P-20 solar panel with power 230W from LDK Company is adopted for the design in this study as it is used in Edinburgh College Solar farm.
- An Excel spreadsheet has been used to deduce the slope irradiation from the measured horizontal and diffuse irradiation values.
- The maximum and minimum cell temperatures are determined to be 29˚C and 1˚C respectively in Edinburgh. This leads to the modules are expected to work with a good efficiency band and produces higher energy.

- Dust and dirty have a huge impact on modules' efficiency reaches to 90% lower output. So, frequently cleaning of modules and maintenance is highly required.
- Sunny Central 1000CP XT inverter from SMA has been used for its high output power, more than 1MKVA, to connect the arrays with the national grid.
- 45 inverters plus 217665 PV panels represent the whole project. Each 4837 panels connected to one inverter as a complete substation.
- The project is expected to cost around 43£m. The costs will be covered after around 21 years.
- The study offers a good solution for cutting the carbon emissions from different points of view. In terms of using the zero carbon emission cars such as electric vehicles and charging these cars via sustainable green energy source such as PV solar panels.
- More than 39.5Ktonnes of CO2 emissions is expected to cut every year.
- It is recommended to use only one type of modules for the whole farm or at least do not mix different kinds of modules in the same array.

The UK has around 45,000 EV, light-duty EV, which is still a very small number, less than 0.5% of UK conventional cars, with respect to 35 million cars registered in Great Britain in 2013 with only 1100 EV exist in Scotland. Around half of the charging units in Scotland are not used according to the BBC report in 13 February 2015. In other words, electric cars still in its cradle stage and need a lot of effort from the government to draw the people's attention to EV. Deep researching is still needed about using these cars in the Middle East and hot countries in general, in terms of batteries which can work in harsh conditions and their capacities that last long for long distances in countries have large area such as Saudi Arabia. Forecasting of solar power is a very important research area which is still need deep researching to convince government and companies and solar energy and renewable energy in general.

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