Dye synthesized solar cell for the emissions of Co2

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Abstract

The production of power using solar panels is often regarded as having no CO2 emissions. A deeper examination of the solar panel system's life cycle, however, reveals that the process energy needed to produce the solar panel itself—which needs energy input from a fossil power plant—is the major activity that contributes to CO2 emissions. The CO2 emissions produced throughout the manufacture process should ideally be significantly lower and able to offset the CO2 emissions produced after the solar panel has operated. With 1643.28 kg of CO2 per m2 of dye solar cell (DSC) panel after 20 years of solar panel life, this paper highlights the amount of CO2 saved. This third generation PV's emissions of CO2 were found to be almost 50% lower than those of silicon-based PV when compared to the published statistics.

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INTRODUCTION

Fossil fuels now provide the majority of the world's energy and are expected to do so until 2030, accounting for 83% of the total growth in energy demand between 2004 and 2030 [1]. The Intergovernmental Panel on Climate Change (IPCC) forecasts that the world's energy consumption would increase by a factor of five over the next century, from 10 TW to about 46 TW by 2100 [2]. The energy-related carbon dioxide (CO2) emission concerns have increased as a result of the burning of this fossil fuel [2–5]. According to the International Energy Agency (IEA), the global CO2 concentration is expected to rise by 14.3 Gt by 2030 compared to 2004 [4]. The increase of the average world temperature by approximately 6°C by the year 2100, according to Boercker et al., is one of the principal effects of rising human CO2 [2]. Such a sharp increase would result in the polar ice caps melting and the seas thermally expanding, causing storms and flooding.

Renewable energy must be used as a substitute carbon-free energy source to fulfil the continuously rising global energy demand in order to prevent the catastrophic effects of global warming. It is thought that renewable energy sources like solar, geothermal, hydro, wind, and biomass can provide all of the world's energy needs. Between 2010 and 2050, the utilisation of renewable energy sources will result in a reduction in greenhouse gas emissions of 220 to 560 Gt of CO2 [6].

Solar power is seen as plentiful and clean in comparison to other renewable energy sources, which is advantageous for its growth as another top competitor for renewable energy. The first generation of solar technology, which is mostly silicon-based solar photovoltaic, controls around 86% of the market for solar energy today (PV). This is because commercial crystalline silicon solar panels only achieve an efficiency of around 15%, but the greatest efficiency ever measured for a laboratory cell is 24.7% [7]. First-generation solar PV systems need high purity silicon, necessitating advanced semiconductor technology. Even though solar PV is thought to provide clean, green energy, the process of making solar PV does produce CO2.

Despite being clean and environmentally friendly, the production of these solar PV does produce CO2. The third generation of solar technology, dye-sensitized solar cell (DSC), is significantly more straightforward to produce than the first and second generations of solar technology, requires less complex and advanced semiconductor technology, and has a reduced manufacturing cost of nearly 30–40% [8]. Although DSC's conversion efficiency (usually 10%–12%) is lower than that of the best thin-film cells, theoretically, its price/performance ratio (kWh/(m2 annumdollar)) ought to be low enough to enable them to compete with electrical production that uses fossil fuels. Due to the inexpensive raw materials, low processing costs, and low energy usage, the payback period for DSC is also shorter. Based on the latter component, it is anticipated that the CO2 produced by producing DSC will be far less than that produced by producing silicon PV.

Therefore, the purpose of this research is to assess the CO2 emissions from the glass substrate-based DSC module manufacturing process. The overall CO2 savings were also computed using the total CO2 emissions from the DSC manufacturing process and the total CO2 emissions that would result from utilising fossil fuels as the energy source to generate the same amount of power. Evaluation of CO2 emission from dye solar cells refers to the process of measuring and analyzing the carbon dioxide (CO2) emissions produced during the production and use of these solar cells. The purpose of this evaluation is to determine the environmental impact of using these cells and to identify opportunities for reducing emissions.

Dye solar cells are a type of photovoltaic cell that uses organic dyes as the light-absorbing material. They have been developed as an alternative to traditional silicon-based solar cells and offer a number of advantages, including lower costs and greater flexibility. However, the production and use of dye solar cells also generates CO2 emissions, which contribute to global warming and climate change.

The evaluation of CO2 emissions from dye solar cells involves assessing the emissions produced during the production process, including the manufacture of materials, the assembly of the cells, and the transportation of the cells to the final location. It also involves assessing the emissions produced during the use of the cells, including the energy required to run the supporting systems, such as pumps and fans.

The results of this evaluation can be used to identify opportunities for reducing emissions and to develop strategies for improving the environmental impact of dye solar cells. This information can also be used to compare the environmental impact of different types of solar cells and to support the development of policies and regulations aimed at reducing the carbon footprint of the energy sector. The scope of the evaluation of CO2 emissions from dye solar cells involves assessing the sources and magnitude of CO2 emissions associated with the production and use of these cells. The following areas are typically included in the scope of the evaluation:

1. Production process: The evaluation includes an analysis of the CO2 emissions produced during the production of the materials used in the cells, the assembly of the cells, and the transportation of the cells to the final location.
2. Use of the cells: The evaluation includes an analysis of the CO2 emissions produced during the use of the cells, including the energy required to run the supporting systems, such as pumps and fans.
3. Life cycle analysis: The evaluation includes a life cycle analysis, which takes into account the CO2 emissions produced over the entire lifecycle of the cells, from the extraction of raw materials to the disposal of the cells at the end of their useful life.
4. Comparison with other energy sources: The evaluation includes a comparison of the CO2 emissions produced by dye solar cells with those produced by other energy sources, such as fossil fuels and traditional solar cells.
5. Policy and regulatory implications: The evaluation includes an analysis of the policy and regulatory implications of the CO2 emissions produced by dye solar cells, including the impact on energy policies and the development of regulations aimed at reducing the carbon footprint of the energy sector.

The scope of the evaluation of CO2 emissions from dye solar cells is designed to provide a comprehensive understanding of the environmental impact of these cells and to support the development of strategies for reducing emissions and improving their environmental performance. Despite the potential advantages of dye solar cells, there is a growing concern about the environmental impact of these cells, particularly in terms of the CO2 emissions they generate during production and use. The purpose of this evaluation is to understand the sources and magnitude of CO2 emissions associated with dye solar cells and to identify opportunities for reducing emissions and improving the environmental performance of these cells.

This problem statement highlights the need to address the environmental impact of dye solar cells and to understand the sources and magnitude of CO2 emissions associated with these cells. It also identifies the goal of the evaluation, which is to identify opportunities for reducing emissions and improving the environmental performance of these cells. This problem statement sets the stage for a comprehensive evaluation of CO2 emissions from dye solar cells and provides a framework for understanding the purpose and importance of this research.

Environmental impact of these cells and to identify opportunities for reducing emissions and improving their environmental performance. The following are some of the specific objectives that might be included in the aim of this evaluation:

1. To quantify the CO_2 emissions produced during the production and use of dye solar cells.
2. To identify the key sources of CO_2 emissions associated with these cells, including the production of materials, the assembly of the cells, and the energy required to run the supporting systems.
3. To conduct a life cycle analysis of the CO_2 emissions produced over the entire lifecycle of the cells, from the extraction of raw materials to the disposal of the cells at the end of their useful life.
4. To compare the CO_2 emissions produced by dye solar cells with those produced by other energy sources, such as fossil fuels and traditional solar cells.

5. To identify opportunities for reducing CO_2 emissions associated with dye solar cells, including the development of new materials, improvements in production processes, and the optimization of energy consumption.
6. To evaluate the policy and regulatory implications of the CO_2 emissions produced by dye solar cells and to support the development of policies and regulations aimed at reducing the carbon footprint of the energy sector.

LITERATURE REVIEW

But there are a number of studies that have been published on this topic in recent years. The following are some of the key areas that have been addressed in the literature on this topic:

1. Production process: Several studies have focused on the CO_2 emissions produced during the production of materials used in dye solar cells, the assembly of the cells, and the transportation of the cells to the final location. These studies have provided valuable information on the sources and magnitude of CO_2 emissions associated with the production process.
2. Use of the cells: Some studies have addressed the CO_2 emissions produced during the use of dye solar cells, including the energy required to run the supporting systems, such as pumps and fans. These studies have provided insights into the energy consumption associated with these cells and the potential for reducing emissions through the optimization of energy consumption.
3. Life cycle analysis: A number of studies have conducted life cycle analyses of dye solar cells, taking into account the CO_2 emissions produced over the entire lifecycle of the cells, from the extraction of raw materials to the disposal of the cells at the end of their useful life. These studies have provided valuable information on the environmental impact of these cells over their entire lifecycle.
4. Comparison with other energy sources: Some studies have compared the CO_2 emissions produced by dye solar cells with those produced by other energy sources, such as fossil fuels and traditional solar cells. These studies have provided valuable information on the relative environmental impact of these different energy sources.
5. Policy and regulatory implications: Some studies have addressed the policy and regulatory implications of the CO_2 emissions produced by dye solar cells, including the impact on energy policies and the development of regulations aimed at reducing the carbon footprint of the energy sector.

Ahmed Elshafie and Fikry K. Hassan conducted a life cycle assessment of dye-sensitized solar cells and found that while they have a low carbon footprint during operation, the production and disposal stages of their life cycle can contribute significantly to CO_2 emissions. Another study by Fan-Yun Sun, Chien-Tsung Lu, Wei-Chih Lin, and Sheng-Lung Chen compared the CO_2 emissions from photovoltaic and dye-sensitized solar cells and found that the latter have a higher carbon footprint due to the production of the sensitizing dyes.

Zhongjie Wang, Wei Cai, Zhiyong Fan, and Guoying Chen conducted an environmental assessment of photovoltaic and dye-sensitized solar cells, while Wei Gao, Bin Chen, and Yupeng Wang focused on the environmental life cycle assessment of dye-sensitized solar cells. Manuel M. Torres, João B.P. Soares, and José A. Diniz da Costa compared the environmental impact of the production of photovoltaic and dye-sensitized solar cells using a life cycle assessment method.

These studies provide insights into the environmental impact of dye solar cells and highlight the need for further research to reduce their carbon footprint and make them more sustainable.

METHODOLOGY

The study was started by identifying the process route and equipment involved in the fabrication of DSC panel at DSC laboratory in University Teknologi PETRONAS, Malaysia. The energy consumption was calculated based on the production of 24 units of DSC panel with size of 180 cm x 100 cm which require 48 pieces of FTO coated glass. Figure 1 shows the process flow diagram starting from synthesis of TiO2 photoelectrode materials until DSC panel integration. Few pictures are also included to describe the activities and equipment involved. The synthesis of photoelectrode material involves hydrothermal process, centrifugation, calcination and conversion to paste using three roll mills. During glass substrate preparation, the FTO coated glass will undergo laser marking, sandblasting for counter electrode (CE) side, beveling process, washing and firing. The substrate will then be printed with silver conductor paste followed by drying process. After that, the working electrode (WE) side was printed with prepared TiO2 photoelectrode paste, dried in belt furnace before printed with the second layer of TiO2 to make up for about 10-12 μm thick of photoelectrode films.

The WE was then dried once again before the firing process at 500°C and dye soaking in Ruthenium (Ru) based synthetic dye for overnight. The excess dye need to be clean in order to ensure high performance of fabricated DSC panel.

On the other hand, the CE side was printed with platinum (Pt) which will act as the catalyst in the redox process of the electrolyte in a DSC. The Pt printed CE need to be dried before firing process at temperature of about 420°C. Both WE and CE were assembled in sandwich configuration. Sealing and interconnect machine was used in this process to seal and draw electrical connection between the cells in a panel. The assembled panels were dried in a convection oven to ensure perfect curing of the sealant. Then, an electrolyte was injected through the hole prepared earlier through sandblasting process at the CE side. The holes were then sealed and ultrasonic soldering was used to connect wiring to the integrated panels.

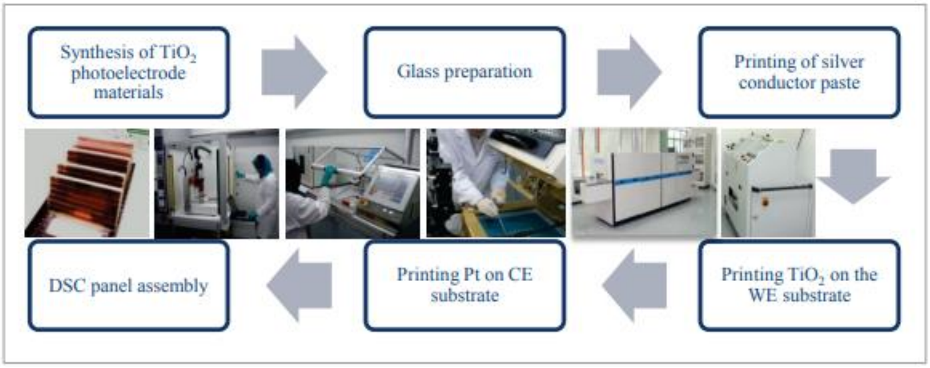
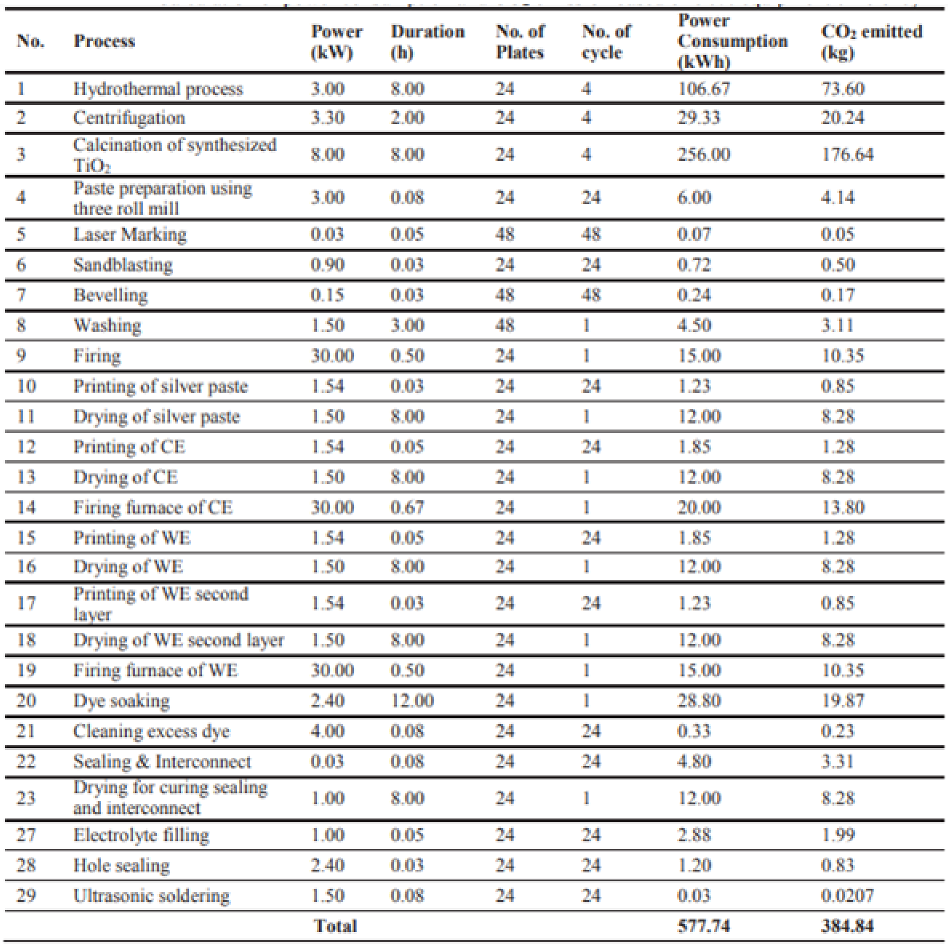


Figure 1: Complete DSC production process

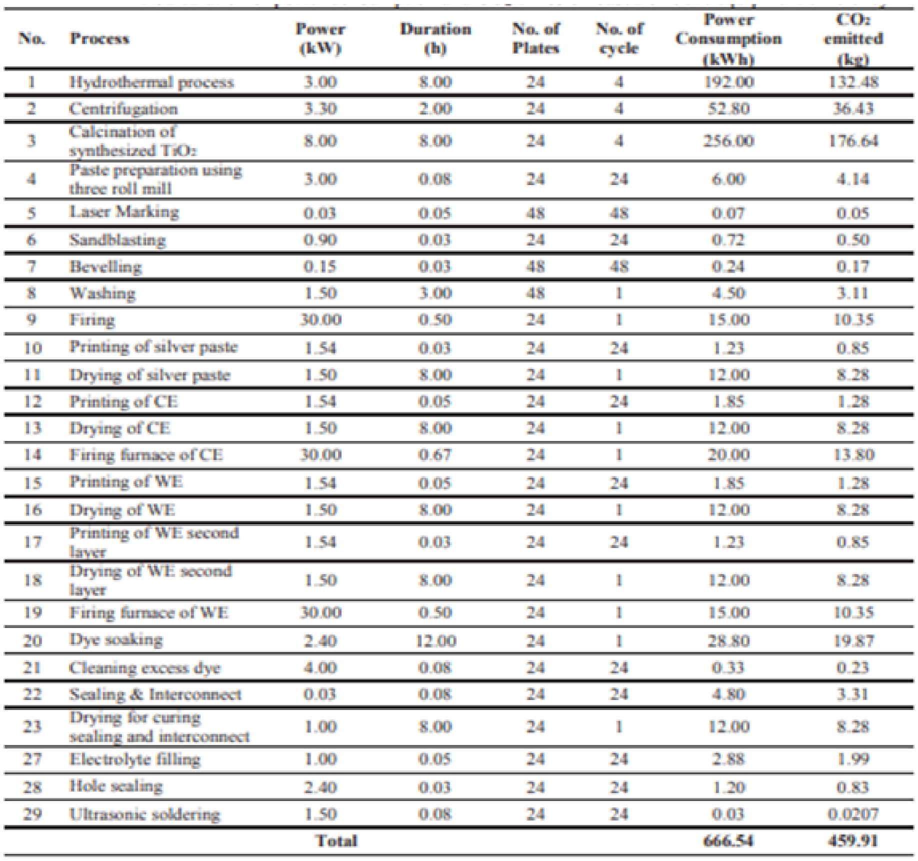
Table 1 and 2 summarized the information such as the equipment power, process duration, number of cycles involved in the production of 24 DSC modules. The table also listed the calculated power consumption and CO_2 emitted by each process steps. The equipment power was obtained from the equipment specifications, assuming the power efficiency to be lowest at 50% and maximum at 90% of energy consumption.

TABLE 1: Calculation of power consumption and CO_2 emission based on 90% equipment efficiency



No.	Process	Power (kW)	Duration (h)	No. of Plates	No. of cycle	Power Consumption (kWh)	CO_2 emitted (kg)
1	Hydrothermal process	3.00	8.00	24	4	106.67	73.60
2	Centrifugation	3.30	2.00	24	4	29.33	20.24
3	Calcination of synthesized TiO_2	8.00	8.00	24	4	256.00	176.64
4	Paste preparation using three roll mill	3.00	0.08	24	24	6.00	4.14
5	Laser Marking	0.03	0.05	48	48	0.07	0.05
6	Sandblasting	0.90	0.03	24	24	0.72	0.50
7	Bevelling	0.15	0.03	48	48	0.24	0.17
8	Washing	1.50	3.00	48	1	4.50	3.11
9	Firing	30.00	0.50	24	1	15.00	10.35
10	Printing of silver paste	1.54	0.03	24	24	1.23	0.85
11	Drying of silver paste	1.50	8.00	24	1	12.00	8.28
12	Printing of CE	1.54	0.05	24	24	1.85	1.28
13	Drying of CE	1.50	8.00	24	1	12.00	8.28
14	Firing furnace of CE	30.00	0.67	24	1	20.00	13.80
15	Printing of WE	1.54	0.05	24	24	1.85	1.28
16	Drying of WE	1.50	8.00	24	1	12.00	8.28
17	Printing of WE second layer	1.54	0.03	24	24	1.23	0.85
18	Drying of WE second layer	1.50	8.00	24	1	12.00	8.28
19	Firing furnace of WE	30.00	0.50	24	1	15.00	10.35
20	Dye soaking	2.40	12.00	24	1	28.80	19.87
21	Cleaning excess dye	4.00	0.08	24	24	0.33	0.23
22	Sealing & Interconnect	0.03	0.08	24	24	4.80	3.31
23	Drying for curing sealing and interconnect	1.00	8.00	24	1	12.00	8.28
27	Electrolyte filling	1.00	0.05	24	24	2.88	1.99
28	Hole sealing	2.40	0.03	24	24	1.20	0.83
29	Ultrasonic soldering	1.50	0.08	24	24	0.03	0.0207
		Total				**577.74**	**384.84**

TABLE 2. Calculation of power consumption and CO2 emission based on 50% equipment efficiency



No.	Process	Power (kW)	Duration (h)	No. of Plates	No. of cycle	Power Consumption (kWh)	CO_2 emitted (kg)
1	Hydrothermal process	3.00	8.00	24	4	192.00	132.48
2	Centrifugation	3.30	2.00	24	4	52.80	36.43
3	Calcination of synthesized TiO_2	8.00	8.00	24	4	256.00	176.64
4	Paste preparation using three roll mill	3.00	0.08	24	24	6.00	4.14
5	Laser Marking	0.03	0.05	48	48	0.07	0.05
6	Sandblasting	0.90	0.03	24	24	0.72	0.50
7	Bevelling	0.15	0.03	48	48	0.24	0.17
8	Washing	1.50	3.00	48	1	4.50	3.11
9	Firing	30.00	0.50	24	1	15.00	10.35
10	Printing of silver paste	1.54	0.03	24	24	1.23	0.85
11	Drying of silver paste	1.50	8.00	24	1	12.00	8.28
12	Printing of CE	1.54	0.05	24	24	1.85	1.28
13	Drying of CE	1.50	8.00	24	1	12.00	8.28
14	Firing furnace of CE	30.00	0.67	24	1	20.00	13.80
15	Printing of WE	1.54	0.05	24	24	1.85	1.28
16	Drying of WE	1.50	8.00	24	1	12.00	8.28
17	Printing of WE second layer	1.54	0.03	24	24	1.23	0.85
18	Drying of WE second layer	1.50	8.00	24	1	12.00	8.28
19	Firing furnace of WE	30.00	0.50	24	1	15.00	10.35
20	Dye soaking	2.40	12.00	24	1	28.80	19.87
21	Cleaning excess dye	4.00	0.08	24	24	0.33	0.23
22	Sealing & Interconnect	0.03	0.08	24	24	4.80	3.31
23	Drying for curing sealing and interconnect	1.00	8.00	24	1	12.00	8.28
27	Electrolyte filling	1.00	0.05	24	24	2.88	1.99
28	Hole sealing	2.40	0.03	24	24	1.20	0.83
29	Ultrasonic soldering	1.50	0.08	24	24	0.03	0.0207
		Total				**666.54**	**459.91**

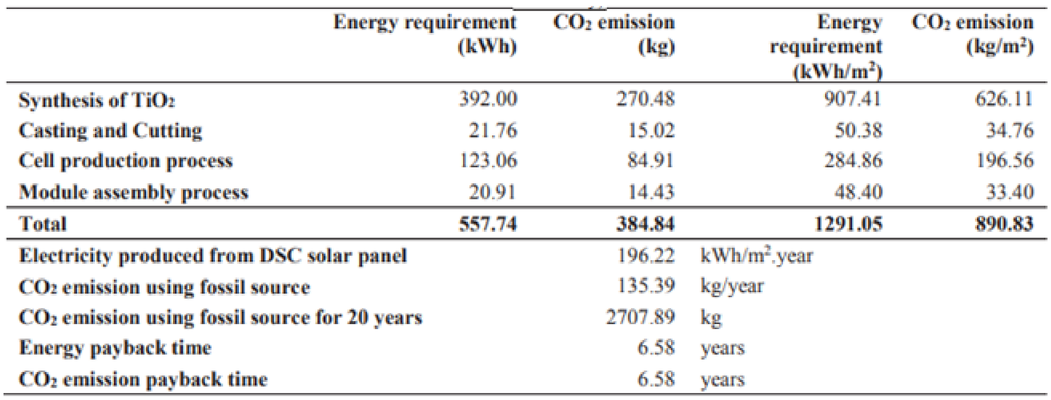
RESULT & DISCUSSION

In this study, CO2 emission from the production of DSC panel was calculated based on the following assumptions:

1. Twenty four sets solar modules being produced per batch.
2. Active area of the module is 80%.
3. Size of 1 module is 0.1 m x 0.18 m.
4. One set of solar module generates 1 W of electricity.
5. Life span of DSC for 20 years.
6. Average solar irradiation is taken as 12 h per day and 365 days per year.
7. CO2 emission equivalence for Malaysia’s electricity consumption is 0.69 kg/kWh.
8. Efficiency of all equipment involved in DSC production is assumed lowest to be at 50% and highest at 90%.

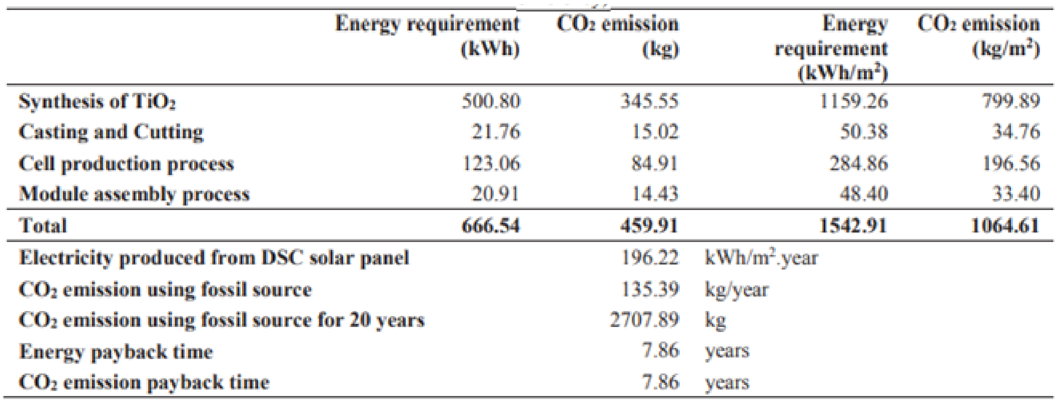
Table 3 and 4 summarized the calculated data based on 90% and 50% equipment efficiency, respectively. Based on 1 m2 of DSC solar panel production, the required energy during the production process is 1291.05 kWh with CO_2 payback time at 6.58 years. At 50% equipment efficiency, higher energy is required for the production which is 1542.91 kWh with longer CO2 payback time at 7.86 years.

TABLE 3. Calculated electricity production from DSC and CO2 savings based on 1 m2 of DSC solar panel (90% of equipment efficiency)



	Energy requirement (kWh)	CO_2 emission (kg)	Energy requirement (kWh/m^2)	CO_2 emission (kg/m^2)
Synthesis of TiO_2	392.00	270.48	907.41	626.11
Casting and Cutting	21.76	15.02	50.38	34.76
Cell production process	123.06	84.91	284.86	196.56
Module assembly process	20.91	14.43	48.40	33.40
Total	**557.74**	**384.84**	**1291.05**	**890.83**
Electricity produced from DSC solar panel		196.22	kWh/m^2.year	
CO_2 emission using fossil source		135.39	kg/year	
CO_2 emission using fossil source for 20 years		2707.89	kg	
Energy payback time		6.58	years	
CO_2 emission payback time		6.58	years	

TABLE 4. Calculated electricity production from DSC and CO2 savings based on 1 m2 of DSC solar panel (50% of equipment efficiency)



	Energy requirement (kWh)	CO_2 emission (kg)	Energy requirement (kWh/m^2)	CO_2 emission (kg/m^2)
Synthesis of TiO_2	500.80	345.55	1159.26	799.89
Casting and Cutting	21.76	15.02	50.38	34.76
Cell production process	123.06	84.91	284.86	196.56
Module assembly process	20.91	14.43	48.40	33.40
Total	**666.54**	**459.91**	**1542.91**	**1064.61**
Electricity produced from DSC solar panel		196.22	kWh/m^2.year	
CO_2 emission using fossil source		135.39	kg/year	
CO_2 emission using fossil source for 20 years		2707.89	kg	
Energy payback time		7.86	years	
CO_2 emission payback time		7.86	years	

From the above data, hydrothermal and calcination process are the two major energy demanding processes which caused higher CO2 emission. These two processes are very much needed to produce nanocrystalline photoelectrode material with improved efficiency [9]. A study conducted by Kato et al., [10] reported that the energy requirement for 1 m2 of c-Si PV module was 11673 MJ (3242.53 kWh/m2). By taking this amount of energy, and using the CO2 emission factor in Malaysia, the CO2 emission from the production of c-Si PV module is 2237.34 kg CO2/m2 . Comparing the reported value with the highest CO_2 emission from DSC solar panel production based on 50% equipment efficiency (1064.61 kg CO_2/m^2) shows CO_2 savings of 1172.73 kg. Thus, it is safe to conclude that DSC solar panel has significant reduction in CO_2 emission to the atmospheric as compared to the silicon PV module. In addition, the energy payback time for silicon PV module is longer with estimation of 12 years.

The result obtained from this study also in good agreement with a study done by Parisi et al. [11]. Based on their study, DSC shows an energy saving in the range of 48% to 66% with 49% to 79% reduction of CO_2 emission. This correspond to a minimum of 8 months and maximum of 14 months of energy payback time compared to other solar PV.

CONCLUSION

DSC solar panel produced clean energy, but the production process requires energy which contribute towards the increase of atmospheric CO_2. However, this type of solar panel proves to be a better option as compared to direct utilization of electricity from fossil power plant with reduced emission of approximately 1643.28 kg CO_2 for 1 m2 of solar panel. In addition, the production of silicon PV module requires higher amount of energy which directly contributes to higher CO_2 emission. High amount of CO_2 savings for DSC solar panel production was based on the lab scale production equipment which has low power consumption. For mass production of the DSC solar cell, industrial scale equipment is recommended. However, the encouraging result from this study has strengthened the assumption that DSC is an environmentally and economically viable alternative energy sources. With its significant advantages [12, 13], DSC technology will remain a sustainable alternative to generate electricity given that its efficiency is continuously improved through various approaches [14, 15, 16].

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