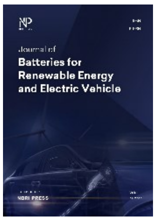
Journal of Batteries
for Renewable Energy and Electric Vehicles (JBREV)

Journal homepage: https://journal.n-bri.org/



Potential Application of Carbon Quantum Dots (CQD) Synthesis from Rice Husk Waste Composite as Advanced Solar Cells to Increase Photon Energy Absorption in Maximizing Solar Panels Power Output Production

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ARTICLE INFO

Article history:
Received date 14 January 2023
Received in revised form 06 April 2023
Accepted 08 May 2023

Keywords:
Carbon Quantum Dots (CQD)
Solar Cells
Energy Absorption

ABSTRACT

The increase in national energy consumption has forced us to intensify renewable energy utilization. Solar panel is one optional answer for that purpose. Unfortunately, the product resistance and photon absorption from silicon-based solar cells are still not good enough. Carbon quantum dots (CQD) could be an alternative advanced material that can be utilized to maximize the performance of solar panels. Therefore, researchers are interested in finding out how to manufacture CQD from the synthesis of rice husk waste composite as an advanced solar cell and analyze its potential to maximize solar panel photon energy absorption. Researchers use mixed study that applies literature review methods (as part of the descriptive research aspect) and causal comparative research methods (as part of the quantitative aspect). Based on previous research, rice husk waste was pre-processed by washing using de-ionized water (DI water) to remove residue, then baked and blended into powder, and cleaned using HCl as impurities remover. The hydrothermal process was carried out at 190 °C for 12 hours to synthesize CQD which functioned by amino and carboxyl. For further purification, CQD was dialyzed against DI water in cellulose. Super-dense material due to quantum level compression, makes CQD have a higher resistance when compared to silicon as solar cells. In addition, the absorption of photon energy that can be done by CQD solar cells has a higher percentage when compared to conventional solar cells. However, in this paper, the researchers did not make CQD and only analyzed through modeling which became the research gap in this paper.

INTRODUCTION

The increase in national energy consumption by 3.4% [1] in the last year has forced us to intensify the utilization of alternative energy sources that we have. The failure to achieve energy decentralization as a whole—amid an increasing need for similar things—makes us increasingly need optimization of EBT exploration [1-3]. Net Zero Emissions, Sustainable Development Goals (SDGs), and—most recently—COP27 are goals that various countries in the world are trying to achieve, including Indonesia [2-4]. Several meetings have been held and various agreements have been agreed to create a better world by realizing various things that make our earth habitable. The transition to clean and renewable energy in realizing sustainable development and zero net emissions is one of the steps that we are taking together [3,5]. This clean energy transition is not just a discourse, but a necessity for all of us. The Indonesian government has started to pay attention to the energy transition in Indonesia, which initially only relies on fossil energy and is starting to switch to clean energy (little by little) [6-7].

Referring to the International Energy Agency (IEA), clean and renewable energy is energy that comes from natural processes that are replenished continuously and can be continuously produced

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DOI: 10.59046/jbrev.v1i01.10

without having to wait a long time. Indonesia's New Renewable Energy (NRE) potential is quite large, including mini/micro hydro of 450 MW, Biomass of 50 GW, wind energy of 3-6 m/s, and solar energy of 4.80 $kWh/m^2/day$ [8-10].

The Indonesian government's serious steps towards the realization of this target have begun through policies issued in the last five years. In 2006, the Government of Indonesia issued Presidential Regulation Number 5 Year of 2006 concerning the National Energy Policy. Through this regulation, the contribution of NRE is targeted to be divided into biofuels of more than 5%, geothermal of more than 5%, and other NRE (especially Biomass, Nuclear, Small-Scale Hydropower, Solar Power, and Wind Power) by more than 5%. Other government policies are stated in Government Regulation Number 79 Year of 2014 concerning the National Energy Policy which regulates the target of NRE in 2025 of 23% and EBT in 2050 of 31% and Presidential Regulation Number 22 Year of 2017 concerning the National Energy General Plan. Existing targets and commitments certainly cannot be realized simply by formulating and establishing policies. There needs to be encouragement from the application of established technology with continued development to realize our dreams regarding sustainable development and net zero emissions. One way is to harvest solar energy through solar panels.

Solar panels are not new, their application has spread widely both in the form of commercial products and further developments based on the results of ongoing research [11-13]. This existing technology needs to be developed further by optimizing the work of solar panels to maximize the energy that can be generated and distributed to the community [11]. One of the main problems that hinder the application of solar panels in society is that the amount of power output produced is still not comparable to existing conventional electric power [11, 14-15].

The resulting power output is closely related to the absorption of photon energy carried out by solar cells in solar panels [15]. The greater the photon energy that can be absorbed, the greater the possibility of power that can be generated. If the amount of energy generated from the same solar panels is greater, then the efficiency potential of solar panel technology can also be maximized so that the power distributed to the community can be more massive [15-16]. This can then be a breath of fresh air for local energy security which carries the concept of clean and renewable energy. However, unfortunately, the energy absorption of existing solar panels is still not optimal. This is because the main materials that make up conventional solar cells as the main components of solar panels still have gaps in thermal conductivity [17-18]. In addition, the relatively non-durable and non-compact nature of silicon means that the durability and feasibility of applying solar panels can still be developed further [20]. This advanced development can be started by looking for alternative materials which are also advanced materials to become the main material for solar cells. Carbon quantum dots (CQD) is one of the answers to this. CQD are a class of carbon nanoparticles that have photoluminescence properties [21]. Making CQD must also consider aspects of sustainability and environmental sustainability [22-23]. Therefore, the raw material to be processed into CQD must come from something that is no longer used or has no functional use value [22]. One of the materials that can be considered for this is the waste that exists in various industrial sectors, one of which is agriculture [22]. In the agricultural sector, there is a waste rarely used even though the amount is quite abundant, namely rice husk waste.

Rice husk waste is used to manufacture carbon structures on nano to the quantum scale, which has been developed in recent years and is processed at a relatively low cost [24-26]. Nanoparticle and quantum-sized materials such as graphene, carbon nanotubes, carbon quantum dots, and carbon nanofibers have great energy potential [21,23]. Various research methods regarding the synthesis of rice husk materials into nanoparticles and quantum-sized objects have high value because the synthesis of these materials is most commonly used today with the availability of green technology, low fabrication costs, and ease of modification [22, 25]. The use of rice husk waste discussed in this study has broad applications in various scientific applications due to its electrical, mechanical, thermal, and biocompatibility properties [25-26]. In this study, rice husk waste was chosen as a carbon precursor in synthesizing CQD because it has great potential to be an environmentally friendly method. This is supported by the percentage of carbon composition in rice husk which is around 30% - 50% [25].

With that, rice husk waste is an alternative solution in CQD synthesis and can convert rice husk waste into products that have added value. CQD compensates for the shortcomings of traditional materials in terms of cytotoxicity, environment, and biohazards [26]. In addition, CQD also featured good water solubility, chemical stability, and photobleaching resistance [24,26]. Based on this, the solubility of CQD is said to be very good because it is in the form of liquids and particles on the quantum scale, and also the properties of carbon will certainly increase the hardness of the material. However, what if rice husk waste, which has no use value, can be used further to produce something that accelerates national development in the energy sector? What if rice husk waste is further processed into an advanced material called CQD which is then applied as a material for solar cells in solar panels? Can this increase the utility generated from solar panels?

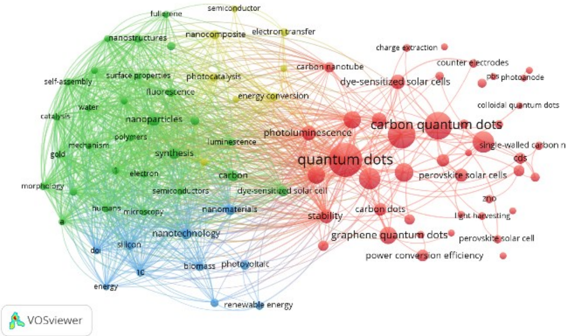

Fig. 1. Visual Map of Carbon Quantum Dots Literature Study Based on Bibliographic Data

Based on this background, the researcher is interested in writing a paper entitled "Potential Application of Carbon Quantum Dots (CQD) Synthesis from Rice Husk Waste Composite as Advanced Solar Cells to Increase Photon Energy Absorption in Maximizing Solar Panels Power Output Production" as an original paper researchers submitted in the Youth Idea Competition (YIC) 2022 Paper Competition organized by the National Battery Research Institute. As for the problems that the researchers are trying to raise in this paper, the researchers formulate them as follows:

1. Can rice husk waste be processed into CQD material? If so, what is the manufacturing process like?
2. Can CQD from rice husk waste composite be applied as an advanced material for solar cells? If so, how do the results of its application compare with silicon-based solar cells?

Based on the formulation of the problem, the researcher proposes a hypothesis for each problem formulation:

Problem Formulation 1

a. H_0: Rice husk waste cannot be processed into CQD material.
b. H_1: Rice husk waste can be further processed into CQD material.

Problem Formulation 2

a. H_0: CQD from rice husk waste composite cannot be applied as an advanced material for solar cells and silicon-based solar cells have maximum application results.
b. H_1: CQD from rice husk waste composite can be applied as an advanced material for solar cells and silicon-based solar cells have application results that can still be rivaled by CQD from rice husk waste composites.
c. H_2: CQD from rice husk waste composite can be applied as an advanced material for solar cells and silicon-based solar cells have application results that cannot be competed with by CQD from rice husk waste composite.

Based on this hypothesis, the researcher formulates the objectives in this paper to be:

1. Knowing the process of making CQD materials based on the results of literature studies;
2. Finding out whether rice husk waste can be made into CQD material and how to make it;
3. Calculating the value of photon energy absorption if CQD from rice husk waste is applied as a solar cell material and estimating the amount of power that can be generated by the solar panel;
4. Comparing the value of photon energy absorption and power output in solar panels that use silicon-based solar cells with solar panels that use solar cells made from CQD rice husk waste.

Researchers limit the study in this paper to several variables which will be explained further in the methodology section. The researcher also limits and emphasizes that in this paper, the researcher did not make the material that the researcher intended directly because of limited time and research funds. However, the researcher plans to continue this research and make the material that the researcher intends and conduct experimental tests in future studies. These things become a number of things that make the research different in this paper with previous research in table x or in other studies that the researcher includes in the bibliography.

This research is expected to provide an overview of the manufacture of CQD using rice husk waste which then the results of the analysis produce energy from CQD which is considered to be able to provide an effective flow of electrical energy by using electric photon absorption of light applied to solar panel work systems. Researchers also saw the potential for rice husk waste by carrying out the CQD extraction process which would later be used further as observation material in research. In previous research, CQD have superconducting properties, which has the potential to be an innovation in the application of CQD in solar panels. The superconductor properties in this study will also be compared with the application of conventional solar panel work systems. In its development, this research is useful as a comparison and innovation in the implementation of solar panels using CQD. This research is expected to provide sustainability innovation as a theoretical development of CQD materials.

The innovation applied in this research is the first step to support and implement aspects of renewable energy, especially the application of solar panel systems. Thus, the material in the form of rice husk and the innovation of its application are expected to provide benefits to the general public.

METHODOLOGY

The research that the researchers did was quantitative research by applying a comparative causal method. This paper can be categorized as quantitative research because the data that is being searched for and trying to obtain is closely related to mathematical constants rather than descriptive analysis. Although in the process, this research also involved several things related to qualitative research, the researcher stated that this paper was part of quantitative research. Based on the research background and the objectives to be obtained, the researcher defines the variables in this study as follows in Table 1.

Table 1. Table of Research Variable Definition

Variable Type	Variable Name
Independent Variable	Type of the solar cells
Dependent Variable	Photon energy absorption Power output generated on the solar panel
Control Variable	Type of the solar panel Solar radiation sample
Confounding Variable	Land cover differences Weather fluctuations Technical glitches

These variables can then be explained further that the type of solar cell in question is based on the main ingredients that make up the solar cell. There are 2 types of solar cells that researchers will try to compare, namely solar cells with a silicon base material (conventional solar cells) and solar cells with CQD based materials from composite rice husk waste (advanced solar cells). Researchers will then analyze how much photon energy can be absorbed from each solar cell when applied to solar panels. This photon energy absorption data will then be used for further calculations in knowing the amount of power output that can be generated. To find out and clarify the existence of a causal relationship between the different types of solar cells used and the amount of photon energy absorption and the resulting power output, the researchers limited a number of things. These things are related to the type of solar panels that researchers make, the same between solar panels that use silicon solar cells and those that use CQD solar cells as the component.

In addition, the researchers also used solar radiation data in the same sample area to obtain an equivalent photon energy absorption ratio. However, there are several other variables that could potentially give different results, but the researchers did not make them one of the calculations and technical considerations in this paper. Some of these variables include differences in land cover, weather fluctuations, and technical disturbances to solar panels. The data in this paper the researchers obtained through literature study methods and practical modeling.

The literature study that the authors conducted in this paper was in the form of a literature review and reduction of secondary data from various previous studies. This method aims to obtain data on how to make CQD materials and how to apply this method in processing rice husk waste into CQD. At the literature study stage, researchers are also trying to find data regarding the size of the photon energy absorption and power output that can be generated from conventional solar cells by analyzing previous studies. Literature studies are also carried out by researchers to obtain data on the types of solar panels and solar radiation which will then be used for practical modeling. As for the practical modeling method, researchers used it to obtain data on the value of photon energy absorption and the amount of power output that can be generated from the same solar panel using solar cells with different materials.

RESULTS AND DISCUSSION

Carbon Quantum Dots (CQD)

Carbon Quantum Dots (CQD) are a class of carbon nanoparticles with sizes below 10 nm [23]. CQD have a great potential of being a replacement for toxic metal-based quantum dots considering its certain distinct properties such as excellent optical absorptivity, high biocompatibility, less toxicity, high solubility in water, photochemical stability, and high photoluminescence (PL) property [24-25]. CQD have various superior properties such as high photoluminescence, easily soluble in water, non-toxic, and very abundant in nature [26-27].

Since the discovery of carbon dot nanoparticles as a new material from carbon, studies on carbon dots have continued to be developed to date. CQD possesses unique physicochemical and photochemical properties making them a promising platform for imaging, environmental, catalytic, biological, and energy-related applications. CQD material can be synthesized from starting materials containing carbon, both simple organic compounds and complex biopolymers.

Several carbon sources have been synthesized into CQD such as garlic, bagasse, and banana peel waste [22]. Carbon chain bonds as the main source in the manufacture of carbon dots are the focus of research that is studied and developed for its application in several applications. Several researchers have made carbon dots from various carbon sources, including using cellulose nanocrystals from empty palm oil bunches, coconut water, and granulated sugar [22, 27].

In general, there are two approaches in synthesizing nanomaterials, namely what is referred to as bottom-up and top-down [28]. The synthesis of nanomaterials with a bottom-up approach makes it possible to control parameters such as size, geometry, doping ratio by various elements, and the degree of agglomeration of the particles. As explained by Nasir *et al.* 2019 [29] that in the bottom-up approach to the process of synthesizing nanomaterials, atomic or/and several molecular species interactions occur through a series of chemical reactions. The precursor is usually a liquid or gas which is ionized, separated, sublimated or evaporated, then condensed to form amorphous or/and crystalline nanomaterials. This approach produces nanomaterials with fewer defects, a homogeneous chemical composition, less contamination and particles with a small size distribution.

In the top-down approach, the initial material is bulk material. In synthesis, materials are broken down into smaller fragments or particles by providing energy from certain energy sources. The energy used can be in the form of mechanical, thermal, or other forms of energy such as laser irradiation. For example, in the use of laser energy, energy is absorbed by the material and converted into chemical and/or thermal energy to break the intermolecular bonds of the bulk material. This approach usually produces particles with a wide distribution of sizes, and is considered to be one of the drawbacks of the top-down method. The bottom-up approach is considered simpler and more precise in the synthesis of particles less than 100 nm, but the top-down approach is preferred for the synthesis of thin films and small particles larger than 100 nm.

CQD's photoluminescence property allows it to be a light absorber in photovoltaics, aligned with its excellence in photon absorption and electron excitation, as well as their tunable energy levels. CQD have an extinction coefficient that is about an order higher than commonly used metal complexes, an extinction coefficient of 105 M^{-1} cm^{-1} [29]. CQD with these tunable photoluminescence properties are desired due to their ability to fulfill the demand of sensing, imaging, and photocatalysis applications. CQD has characteristics of a quasi-spherical carbon nanoparticles and consists of -sp^2 graphitic carbon (also known as graphene) and -sp^3 hybridized carbon (further explains the fluorescence properties of atoms) which allows further investigation on their tunable properties.

Functionalization of CQD is defined as a surface modification process where functional groups are used to enhance the performance of these carbon nanoparticles, tune the photoluminescence, and the band gap of carbon quantum dots. The functionalization agent helps enlarging the band gap between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) [30], resulting in more surface functional particles on CQD's structure which allows further utilization in broad applications and fluorescence shifting.

Table 2. Comparison Table of CQD Surface Area of Rice Husk Waste with Commercial Silica [26]

Material Type	BET Surface Area (m^2/g)
Rice Husk Waste CQD	94.761
Commercial Silica	326.9

This causes CQD to have a much higher density than silica as mentioned in Table 2. Molecular compaction to the quantum level makes the resistance of CQD have a relatively higher value compared to various other materials that exist and are used as materials for solar cells. In addition, the density of this molecule makes the process of transferring heat and energy to CQD faster. This speed of heat transfer makes the absorption of photon energy that can be carried out by CQD in theory also higher than that of silica. These advantages make CQD the potential to be applied as the main material for the manufacture of solar cells. CQD made from waste such as rice husk waste will have better application potential, because there are elements of environmental sustainability and waste treatment to support the realization of zero net emission in the clean energy transition process.

Rice Husk Waste CQD

In this study, rice husks were chosen as the carbon precursor in synthesizing CQD given the background that rice husks are one of the most organic wastes produced during the de-husking or milling process that contains mainly 30-50% carbon.

Hence, making rice husks converted into CQD with superconductor and compact properties a suited solution [25]. First, rice husk waste will be rinsed using de-ionized water (DI water) and then made into charcoal by heating it at 60°C which will produce rice husk ash. Rice husk waste that has undergone a heating process will be cleaned using 0.1 M HCl solvent to remove inorganic impurities. Followed by rinsing again with DI water at 60 °C. Temperature plays a role in giving effect on particle size due to the fact that the hydrothermal process consists of carbonization and dehydration of the carbon core. Thus, based on the literature obtained according to Lin [35], for the synthesis of amino (NCQD) and also carboxyl functionalized CQD (CCQD) a temperature of 190 °C was used for hydrothermal process. In the synthesis of NCQD & CCQD, various volumes of Ethylenediamine (EDA) & ascorbic acid were used between 2.5 ml - 10 ml as functionalization agents for amino & carboxyl groups as shown in Fig. 2 and Fig. 3.

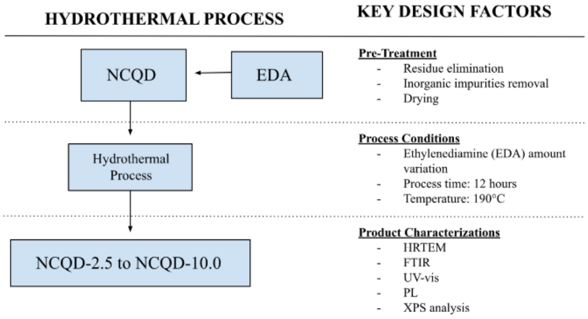

Fig. 2. Hydrothermal process for CQD with amino as functionalization agent and summary of critical design factors

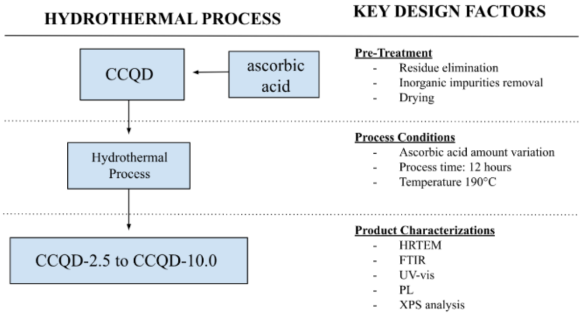

Fig. 3. Hydrothermal process for CQD with carboxyl as functionalization agent and summary of critical design factors

The hydrothermal process was carried out in a Teflon-lined autoclave for 12 hours and underwent a cooling process for 24 hours before being filtered using a vacuum. During the hydrothermal process, rice husks that have been destroyed form carbon material containing rich surface functional groups including hydroxyl and carbonyl aromatic structures, also called as the carbonization process. This means the amount of functionalization agents are directly proportional to the absorption ability. Increasing the amount of functionalization agents leads to larger absorption bands in the range of 3000 - 3500 cm^{-1}. The number of acids added affects the emission wavelength because a high amount of acid enhances the protonation to the negatively charged CQD thus leading to stronger electrostatic interaction in CQD structure [37]. Then NCQD & CCQD will be dialyzed using DI water in the visking tubing for 24 hours. The results obtained will be in the form of NCQD & CCQD character variations in the form of HRTEM, FTIR, UV-sis, PL, and also X-ray Photoelectron Spectrometer (XPS) analysis.

Amino and carboxyl functionalized CQD display that its structure tends to be smaller in size in comparison to the non-functionalized CQD due to the alkaline and acidic condition during synthesis which leads to deprotonation and protonation of CQD, respectively. Both NCQD and CCQD correspond to the interlayer spacing of crystalline graphite, thus affecting the electron density and quantum confinement effect in CQD. The surface area of the CQD of rice husk waste can be obtained through a comparison of the results of the Brunauer–Emmett–Teller (BET) analysis which is 509.5 m^2/g. This specific surface is much lower than 326.9 m^2/g for silica which is usually applied as a base material for solar cells.

The silica content collected with rice straw is much greater than other plants because rice straw contains the following organic matters: Cellulose (32 - 47%, Hemi cellulose (19.27%), Lignin: (5 - 24%), Ash (13 - 20%) [28]. Rice straw ash has 60% silica [29] which, of course, is reported to be different under different climatic conditions, depending on soil type, rice cultivation season, weather conditions, and geography.

Photon Energy Absorption Analysis

In this study, the results of processing rice husk waste will result in the extraction of CQD. Based on previous studies, CQD has an absorption coefficient and a broad spectrum of absorption in photovoltaic and photocatalytic applications. The results show that CQD have high-energy photons at short wavelengths as a result of the absorption of light with π-conjugated electrons in the sp^2 atomic framework. Absorption spectrum CQD has a significant absorption peak at 230 – 320 nm on the UV scale. Based on previous studies, CQD energy absorption was characterized using the UV-Vis method. In that study, CQD 1.0 mg/ml was used which was synthesized using the hydrothermal method.

In general, the optical absorbance peak waves in the UV-Vis characterization of CQD are measured as π-π with sp^2 atomic transitions. The hydrothermal method is used to synthesize CQD into red, green, and blue UV-Vis waves using phenylenediamine isomers [36]. The CQD absorption spectrum will show a wave peak around 230 nm and a shoulder wave around 300 nm. Fig. 4 has shown the fluorescence absorption and emission spectra of several synthesized CQD. From Fig. 4, it can be seen that the synthesized CQD has a very broad spectral absorption range. Based on the use of CQD photocatalysts can be classified into several parts and each of these compounds has different characteristics and performance in absorbing light sources.

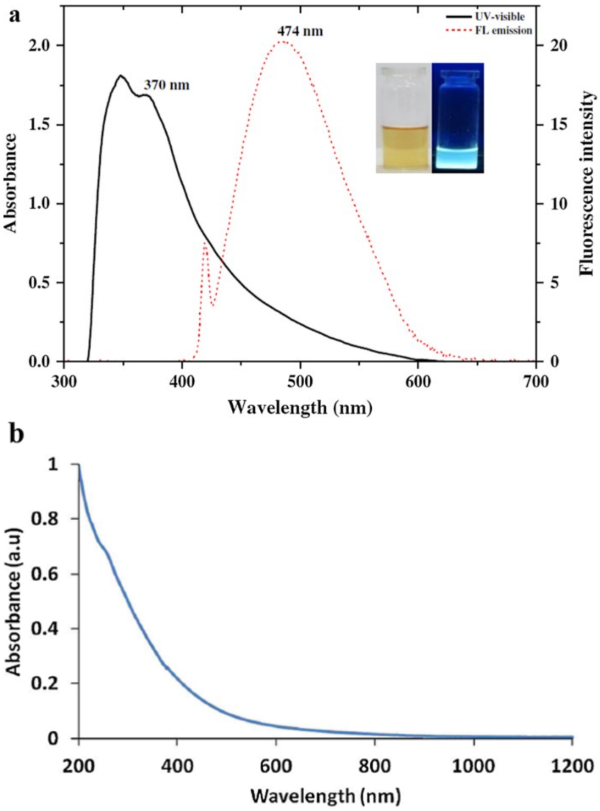

Fig. 4. (a) Illustration of the CQD experiment with UV light (λex = 390 nm) [29] **(b)** UV-Vis spectrum wave with CQD synthesized using dehydration of the precursor g-butyrolactone [30]

In Table 3, CQD is categorized based on photocatalyst based as a measurement to determine the performance of photocatalytic.

Based on literature study, each photocatalyst uses different precursors. Precursors themselves are additional compounds that will react and produce other compounds. Based on previous research, the average CQD synthesis method uses the hydrothermal method because it can affect photocatalytic performance, including increasing electron transfer capabilities, increasing photo center absorption systems, increasing electron blocking systems, and increasing visible light absorption.

Calculation of photovoltaic parameters in dark conditions for solar cells using CQD. The photoelectric conversion mechanism in the dark environment is caused by. storage of solar energy against unabsorbed light. The following is a comparison, which is presented in Table 4. By using the application of photoelectron excitation from CQD and solar cells, experimental conditions using a weather-changing system can continuously generate electricity. Based on this research, a dark efficiency of 14.8% was produced and produced a good long-term effect.

Table 3. CQD-based photocatalyst and their photocatalytic performance table [29]

CQDs-based photocatalyst	Precursor of CQDs	Synthesis Method	Diameters of CQDs	Role of CQD's
Nitrogen doped CQDs/Bi_2WO6	Ammonium citrate and ethylenediamine	Hydrothermal	-8 nm	Increasing light harvesting, improvement in electron transfer ability and better molecular oxygen activation ability
Nitrogen doped CQDs mediated Ag_3PO_4/$BiVO_4$ Z-scheme	$Bi(NO_3)_35H_3O$, NH_4Vo_3, and HNO_3	Hydrothermal	N/A	Electron transfer as collectability of CQDs, improved visible light absorption, CQDs acting as photosensitizer and working ability of CQDs
$PbTiO_3$/CQDs nanocomposites	Sodium citrate and NH_4HCO_3	Hydrothermal	3 - 5 nm	Enhanced absorption of the visible light, enhanced charge separation
a-BI_2O_3/CQDs	L-ascorbic acid and citric acid	Hydrothermal	< 10 nm	Improved light absorption, retarded carriers' recombination
CQDs decorated TiO_2	Citric acid and ethylenediamine	Hydrothermal	5 – 10 nm	CQDs acting as sensitizers to provide visible light response to the nanoparticles
CQDs/Zn^{2+} ions doped -CdS nanowires	Pyrene and HNO_3	Hydrothermal	< 5 nm	CQDs co-catalysts to promote the separation and transfer of photogenerated carriers.

Table 4. The photovoltaic parameters for corresponding all-weather solar cells [33]

Conditions	Heating time of CQDs (h)	Percentage of PCE (%)	Jac (mA cm^{-2})	Vuc (V)	Percentage of FF (%)
Simulated sunlight irradiation (AM 1.5, 100 mW cm^{-3})	No LPPs/9h	0.071	0.271	0.465	56.6
	3	0.011	0.059	0.338	55.6
	4	0.022	0.128	0.386	49.4
	6	0.046	0.198	0.436	54.7
	9	0.074	0.244	0.489	61.9
	12	0.044	0.148	0.485	61.7
	15	0.026	0.122	0.442	48.0
	20	0.022	0.117	0.394	47.5
Dark conditions (0 mW cm^{-3})	No LPPs/9h	0	0	0	0
	3	5.1	0.037	0.226	37.1
	4	7.6	0.053	0.265	32.7
	6	9.6	0.047	0.269	46.0
	9	14.8	0.061	0.332	44.0
	12	10.1	0.078	0.247	31.4
	15	7.3	0.048	0.230	44.8
	20	4.6	0.035	0.207	35.4

In Table 4, measurements of current density voltage (J-V) are measured from simulated solar cell conditions in all weather conditions with an active measurement area of 0.25 cm^2 captured using an electrochemical analyzer (CHI660E) under solar irradiation using a 100-Watt Xenon device. For the light to focus and be directed, a black cell coating is applied to avoid stray light. J-V measurements in dark conditions, solar cells are illuminated by sunlight with a time of about 1 minute. With the process carried out, the electrochemical analyzer will produce cell efficiency values.

Table 5. Comparison table of performance parameters with different concentration of CQD additives [32]

Sample	Jsc (mA cm^{-2})	Voc (V)	FF (%)	PCE (%)
0.02 CQDs				
Ave.	22.49 ± 0.496	1.06 ± 0.014	71.91 ± 3.62	17.15 ± 1.59
Max	22.97	1.086	75.12	18.74
0.04 CQDs				
Ave.	22.95 ± 0.108	1.08 ± 0.007	75.43 ± 2.17	18.81 ± 0.45
Max.	23.13	1.101	75.28	19.17
0.08 CQDs				
Ave.	22.75 ± 0.252	1.04 ± 0.005	69.77 ± 1.54	16.51 ± 0.55
Max	22.61	1.069	69.92	16.90

From the comparison in Table 5, it is known that Power Conversion Efficiency (PCE) is influenced by several factors, namely concentration and also weather conditions. PCE is calculated based on the ratio of incident light power to output electrical power (EP), the higher the PCE, the higher the ability to increase the strength of the EP.

This study also compared the PCE produced by conventional solar cells, based on the results of research conducted in Table 6. Conventional solar cells using a silicone structure produced 10.4% PCE. This states that CQD can also be a comparison with silicon solar cells with a PCE level of 19.17%.

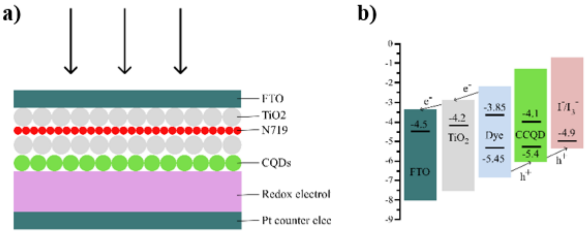

Fig. 5. Scheme of using CQD materials on solar panels system [29]

By doing this research, a solar panel scheme was created based on previous research using CQD with the layer arrangement system shown in Fig. 5 which uses FTO, CQD, TiO$_2$, and Pt electrodes.

Table 6. Selected representative results of graphene/Si heterojunction solar cell efficiency [34]

Solar Cell Structure	PCE (%)	Active Area (cm^2)	J (mA cm^{-2})	Voc (V)	FF (%)	Illumination Intensity
Graphene	1.65	0.1	6.5	0.480	56	100
SOCl2-doped Graphene	2.86	0.28	11.24	0.503	50	100
B-doped + Acid-doped Graphene	3.4	0.1	21.0	0.570	28	100
Acid-doped Graphene	4.35	0.9	17.22	0.495	51	100
TFSA-doped Thin Graphite	8.6	0.9	25.3	0.540	63	100
$AuCl_3$-doped Thin Graphite	7.5	0.25	24.28	0.510	61	100
Acid-doped Graphene	9.3	0.1	17.06	0.550	69	70
Acid-doped Multilayer Graphene	9.6	0.1	16.91	0.480	73	70
Acid-doped Graphene	10.3	0.04	38.86	0.520	55	100
$AuCl_3$-doped Graphene	10.4	0.09	31.56	0.480	63	100
Acid-doped Graphene	10.56	0.04	32.83	0.612	67	100
TiO_2/Acid-doped Graphene	14.5	0.047	32.70	0.570	72	100
Photoelectrochemistry Graphene Fabrics	11.03	0.11	20.73	0.570	65	70
TiO_2/Acid-doped Graphene/GO	12.3	0.09	37.40	0.570	57	100
Acid-doped Direct Growth of Graphene	5.1	0.09	31.0	0.390	42	100
TFSA/Crack-filled Graphene with Au NP	12.3	0.09	22.7	0.560	79	100
TiO_2/$AuCl_3$-doped Graphene/SiO_2	15.6	0.11	36.7	0.595	72	100

CONCLUSION

Based on the results and discussion that the researchers have described in the previous section according to the methodology applied to take into account the relevance of the background to the research the researchers draw the following conclusions:

1. CQD are a class of carbon nanoparticles that have distinct properties and are made by synthesizing nanomaterials.
2. Rice husks are used as a precursor for CQD because it contains high carbon content. Rice husks will be cleaned and went through addition of a variational amount of functionalization agents in the hydrothermal process resulting in CQD with tunable properties.
3. Calculation of energy absorption using a simulation of daytime conditions using sunlight and night. Results that CQD can store and absorb energy with a Power Consumption Efficiency (PCE) of 19.17% and long endurance in storing energy.
4. The energy value of photon absorption in CQD gives better results because CQD is a superconductor and can absorb light well so it will produce better power output compared to conventional solar cells.

Taking into account the potential benefits and further development that exists in this paper, but there are still various shortcomings and limitations of existing research, the researcher provides several recommendations to the following parties:

For Other Researchers

1. The researchers suggest conducting a more mature literature study to determine a more precise process for making CQD from rice husk waste and determine the optimal research instrument;
2. The less than optimal and less specific data processing that has been carried out makes the results of this study less than optimal, therefore the researcher suggests other researchers to do more thorough data processing and carry out several tests before stating the results and discussing these results;
3. The researchers also strongly recommend other researchers to make initial to functional scale materials from CQD made from rice husk waste to then be applied as solar cells in solar panels.

For Solar Panel Manufacturers

1. Because the power output value that can be generated from solar panels that use CQD-based solar cells from rice husk waste is greater than conventional solar panels, the researchers suggest solar panel manufacturers to try to produce solar panels that apply CQD-based solar cells;
2. Due to the feasibility and sustainability analysis that the researchers have not carried out in this paper due to time constraints, the researchers suggest solar panel manufacturers to carry out feasibility tests after implementing the previous suggestions or

work with researchers to develop this research further;

3. To work together and provide more benefits to the community by becoming collectors of rice husk waste from farmers to be further processed into CQD.

For the Government

a. Because of the large potential benefits of this research, researchers suggest the government to pay attention to and consider the development of CQD from production waste such as rice husk waste as a medium for accelerating the national clean energy transition;
b. However, due to the limitations of this study, the researchers suggest the government conduct further research before disseminating this research.

ACKNOWLEDGMENT

The researchers express our deep gratitude to the almighty God, because of his guidance and help the researchers were able to make and complete this paper. Researchers also express special thanks to the parents of each researcher for supporting each research activity. The researcher also expresses his gratitude to colleagues in the department and at the university who made a positive contribution directly or indirectly in the process of making this paper.

AUTHOR CONTRIBUTION

A. H. Wibowo as the First author and S. E. Andoko also I. A. Satya as the Second author equally contributed as the main contributors of this paper. All authors read and approved the final version of the paper.

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