A Framework for a Sustainable and Energy-Efficient University Computing Laboratory

Wisam H. Benamer[1*], *Estabrq* Elhanoshi[2], *Malak* Elferjani[3], and *Esmaeil* H. Alkhazmi[4]

[123] *Information System Department Faculty of Information Technolgy ,University of Benghazi, Libya.*
[4]*Electrical and Electronics Engineerin Departement, University of Benghazi, Libya.*

Abstract. Both carbon footprint and energy consumption remain major global concerns. From this perspective, the current paper aims to design and implement a sustainable, energy-efficient laboratory to reduce carbon emissions and save energy. Furthermore, to emphasize the concept of green computing, the study targeted the Faculty of Information Technology at the University of Benghazi, Libya, as a case study in a large institution intended to serve as a model for others. The proposed system integrates an IoT-based monitoring framework—including ESP8266 microcontrollers, DHT11 sensors, photoresistors, and smart plugs—combined with a solar photovoltaic (PV) power solution consisting of twenty unshaded solar panels with a 30-year lifetime. Within this framework, a green computer laboratory was designed under environmentally friendly specifications to enhance sustainability through automation and intelligent energy management. The results indicated that the total saved carbon emissions reached 436.2 tCO_2 over 30 years, while the performance ratio achieved 86.6%, confirming the system's high efficiency and its potential to serve as a benchmark for future sustainable initiatives in educational institutions.

Keywords— Green computing; IOT; solar energy; carbon emission.

1 Introduction

In the contemporary era the usage of electronic devices became essential everywhere even though with time these devices the damaged ones are turning to e-waste and can threaten the environment. Therefor, Therefore, As worries about the detrimental effects of information and communication technology (ICT) on the environment grew, a concept known as "green computing" was born. Green computing is four directions of Green Computing of designing, manufacturing, and using computing resources in an environmentally friendly way while maintaining overall computing performance and finally disposing in a way that reduces their environmental impact, Green computing aims to maximize the use of electronic devices without causing environmental damage, decrease the use of hazardous materials, improve energy efficiency over the course of a product's lifecycle, and increase the recycling or biodegradability of factory waste and non-functional products. With emphasis on the operational study of data centers, this research seeks to emphasize the significance of green computing in the design of sustainable computer lab [1][2]. Lots of efforts were executed to implement green computing and The ENERGY STAR is one of them, it's a

[*] Corresponding author: *wisam.benamer@uob.edu.ly*

program that was found to enhance energy efficiency and reduce greenhouse gas emissions to protect the environment. Given the fast population growth and rising demand for energy resources, equitable energy use is one of the most significant modern concerns. Given how much energy modern societies depend on for everything from transportation and industry to lighting and heating, it is now crucial to make sure that energy resources are distributed fairly and equally among all people and communities while striking a balance between meeting growing human needs and protecting the environment [3][4]. Green IT has been successfully adopted by institutions both domestically and abroad in recent years. Many industries are now attempting to adopt environmental protection as their primary priority to become more ecologically responsible. Carbon dioxide (CO_2) is released when computers and other electronic gadgets from all businesses use a lot of electricity. This contributes to the emission of greenhouse gases. The primary contributor to climate change is the use of electricity [5][6]. In Libya the environment program still in dangerous because of the large number of emissions that are coming out of electronic devices and electricity usage. Therefore, the current research chooses information technology faculty laboratory at university of Benghazi as a case study to implement a framework that helps reduce the carbon footprint of IT infrastructure while retaining high computing performance by implementing sustainability. with the usage of Photovoltaic System PV Panel. PV Panel is a Device which sunlight into electricity using solar cells the use of semiconductor materials electronics characteristics of P-V conversion is the principle of the solar cells [7]. Even though the power of PV there are still some obstacles facing the system [8]. That is what our research is trying to solve by the proposed system.

The rest of the paper is organized as follows: II. Related work, III. Methodology, IV Experimental Work, and V. Conclusion.

2 Related Work

According to research in [9] examined the growing issue of e-waste management within the framework of adopting green computing methodologies. It defines green computing as the environmentally responsible creation, use, and disposal of technology aimed at minimizing ecological harm. The research established a direct link between effective e-waste management and the promotion of sustainable computing habits, highlighting that proper disposal is critical to maintaining an environmentally sustainable society. While new technologies have improved the feasibility of both green computing and e-waste management, the study emphasized that significant challenges persist and require organizations to prioritize responsible e-waste practices for initiatives to succeed. Finally, the paper suggested future research should focus on areas like virtualization, cloud computing, and carbon footprint reduction to develop more sustainable green computing techniques.

Study in [10] investigated green computing as an important way to reduce the negative environmental implications of the IT business. According to results, this sector accounts for around 2% of global greenhouse gas emissions, which is comparable to the aviation industry. The report also anticipated that by 2030, the IT industry will consume almost 21% of the world's electricity, with an annual rise in energy demand of 5%. The research emphasized the significance of green computing in lowering energy usage and emissions from the computer sector. 74 relevant publications have been examined such as sustainable practices, energy-efficient hardware design, software optimization, and the use of renewable energy sources. Green algorithms have also been shown to reduce the energy usage and carbon footprint of computer systems. The study's findings highlighted the significance of implementing sustainable computing methods to mitigate negative consequences such as petrol emissions, power usage, and e-waste creation.

Research in [11] assessed the ESP8266 Wi-Fi module's applicability for IoT applications. However, many existing networking options present hurdles to smooth integration. Traditionally, gateways were necessary to create Internet connections, but Wi-Fi devices that follow IEEE 802.11 standards provide direct access to existing Wi-Fi networks, increasing connection speed and lowering expenses. The main disadvantage of Wi-Fi is its high energy consumption, which shortens the battery life of IoT devices. Study shaded light on the ESP8266, a low-cost, ultra-low-power Wi-Fi chip, and assesses its performance in IoT contexts. The study looks at how infrastructure characteristics like beacon and DTIM durations affect power usage, packet delivery ratios, and signal strength. Furthermore, it assesses the effect of antenna location, distance, and direction on module coverage and performance. The findings indicate that the ESP8266 module is ideal for battery-powered IoT applications, with a recharge cycle of up to 2134 days using a 1000mAh battery. Transmission times are also evaluated in seconds, demonstrating the module's effectiveness in IoT installations that require dependable and low-power communication.

As mentioned in [12] the study tried to investigate how green computing techniques affect the sustainability of IT services. The main goal was to maximize computing resources while improving overall performance. The research emphasized the significance of using green computing solutions, such as energy management, virtualization, sophisticated cooling technologies, recycling, e-waste disposal, and infrastructure optimization, to achieve sustainability in IT services. It was noted that energy expenditure in IT departments can account for up to 50% of an organization's overall energy expenditure. While green IT practices are acknowledged for their ability to lower both costs and environmental effect, the survey also found that there has been inadequate emphasis on the strategic benefits of sustainable IT services, such as producing value for consumers, organizations, and society. This report analyzed the current literature on sustainable IT, finding major areas for improvement and suggesting critical principles for creating sustainable and cost-effective IT services. It advocates for a more integrated approach to IT sustainability, in which environmental benefits are balanced with long-term profit development for all stakeholders.

Study in [13] investigated the energy consumption issues connected with cloud computing, which is commonly recognized as a vital computing environment. Despite its benefits, cloud computing poses serious problems with energy usage, particularly for electronic resources such as processing units, storage systems, and networking equipment (switches and routers). Furthermore, cooling needs for IT loads during operations drive up energy use. The increased use of cloud computing raises energy expenditure and carbon emissions. The study provided strategies to improve energy efficiency in cloud computing by lowering energy usage in cloud resources. This was accomplished by determining the resource requirements for cloud service calculations. To save energy in cloud data centers, the study suggested turning on just the computing resources that were required while leaving the rest in a low-power mode (sleep or hibernation). This power management solution outperformed typical methods like scheduling, migration, and virtualization of cloud services. Implementing this strategy might result in considerable energy savings, as well as reducing environmental impact and increased sustainability. The study emphasized how intelligent resource selection—based on processing nodes, servers, discs, and networking devices—could improve cloud operations, resulting in lower energy usage and a greener computing environment.

Research in [14] investigated the vital topic of greenhouse gas emissions and their influence in climate change and global warming. Identifying and monitoring the sources and sinks of these gases is critical for scientists and policymakers trying to solve global issues. According to the survey, more than 90% of academics and specialists agree that growing greenhouse gas concentrations are the major cause of environmental warming. The notion of carbon footprint has developed as a groundbreaking approach for raising awareness about the need to minimize greenhouse gas emissions. Carbon dioxide (CO2), a key greenhouse gas, contributes significantly to global climate change. According to the report, CO2 emissions have tripled over the last three decades, owing mostly to fast global economic development, which has resulted in greater energy consumption and, subsequently, higher greenhouse gas emissions. This mechanism amplifies the greenhouse effect, contributing to global warming. The findings emphasize the need for lower CO2 emissions as a crucial approach for combating climate change and dealing with the long-term environmental repercussions of rising greenhouse gas levels.

The article in [15] created a smart house prototype based on IoT technologies using the NodeMCU ESP8266. This technology allows for remote control and monitoring of electrical equipment, boosting home security, particularly when the residents are abroad. It answers frequent worries about not prioritizing home security by automating numerous processes with sensors and IoT connection. The system includes PIR sensors, DHT11 temperature sensors, and magnetic switches, as well as supporting components including fans, lighting, and door locks. The data is processed by the NodeMCU microcontroller and transmitted with a smartphone via the Blynk app. Users may use the app to operate items remotely, such as turning on or off door locks and lights. In addition, the DHT11 sensor checks room temperature, and if it surpasses 30°C, the NodeMCU automatically operates a fan. The magnetic switch sensor monitors window openings, detecting pole distances of more than 3 cm and delivering messages to the user's smartphone via the Blynk app. Testing the prototype revealed that the system efficiently executed its intended duties, providing a practical and dependable solution for smart home automation and security.

As mentioned in [16] the paper emphasized the importance of green computing and green technology in the e-learning, corporate, business, and IT sectors. The study emphasized that e-learning, which uses technology to provide flexible education from anywhere and at any time, has dramatically transformed the education sector by reducing paper consumption and lowering carbon footprint, making it a practical example of green computing implementation. Green computing, often known as green IT, aims to mitigate the negative environmental implications of computer use by implementing ecologically friendly materials and energy-saving solutions. It also strives to minimize energy consumption and dispose of hazardous items in a sustainable manner, making it an important answer to today's environmental concerns. The study investigated how green computing methods might be implemented in many sectors, including educational institutions, businesses, and IT companies. It also highlighted the potential for these strategies to deliver environmental and economic benefits while improving sustainability in these industries. This report emphasizes the need to adopt green technologies as part of worldwide efforts to lessen technology's negative environmental effect.

Comment: previous studies explored that energy waste and gas emissions as global challenges and tried to employee green computing methods to handle the challenges, even though our study tried to implement PV system as a framework towards using green computing in the faculty of information technology at university of Benghazi to reduce the amount of carbon emission and thinking to use low energy waste devices. Therefore, the new study may draw on past research that has demonstrated the necessity of integrating sustainable design and the usage of performance dashboards to increase environmental efficiency. The study can contribute to the area by giving creative ideas that address past obstacles such as cost reduction and improved user interfaces to broaden the scope of green computing applications in various institutions.

3 The Methodology

The study relied on qualitative content analysis as the main method for understanding and interpreting data extracted from various credible sources, including reference books, scientific publications, and earlier research. The academic studies addressed the subject of green computing from multiple perspectives, such as lowering energy consumption, managing electronic waste, and improving environmental efficiency. These studies were published in peer-reviewed scientific journals, in addition to specialized articles from online journals and technological platforms.
The process involved careful selection and screening of relevant documents, followed by coding the textual data into meaningful units representing key themes. These codes were then grouped into broader categories to identify recurring patterns and topics. Finally, the categories were interpreted to derive insights into the main challenges and best practices in sustainable computing.
Building on these insights, the study proposes the design of a sustainable green computer lab at the Faculty of Information Technology, University of Benghazi. The proposed lab integrates an IoT-based energy management system along with a solar power setup to meet its energy needs. This methodology ensures a rigorous and comprehensive approach to both synthesizing existing knowledge and implementing practical, environmentally responsible solutions

4 Experimental work

A green computer lab proposal was designed within the premises of the Faculty of Information Technology at the University of Benghazi under specifications that make it environmentally friendly and contribute to making the environment more sustainable by creating an automation system using the ESP8266 microcontroller, Blink application and smart plugs. The system consists of two sensors responsible for measuring temperature/humidity and brightness level in the lab. This system can be controlled and monitored via Wi-Fi connection directly on the mobile device, making this system an Internet of Things system. The system is programmed in the Arduino IDE and existing libraries for sensors and the link application. The mobile application used to control and monitor the system can display temperature, humidity and bright information in real time remotely. The sun will also be adopted as a renewable source of energy by designing solar panels that cover the lab's energy needs, which in turn contributes to reducing carbon emissions that cause global warming.

- *Connecting to the Cloud (Blynk Cloud)*

Therefore, Blynk was chosen because it is a cloud-based, free, and easy-to-use IoT platform. Blynk comes with a mobile app that makes data visualization easy, reducing the need for constant on-site presence, and devices can be turned on, off, or settings adjusted from anywhere over the internet.

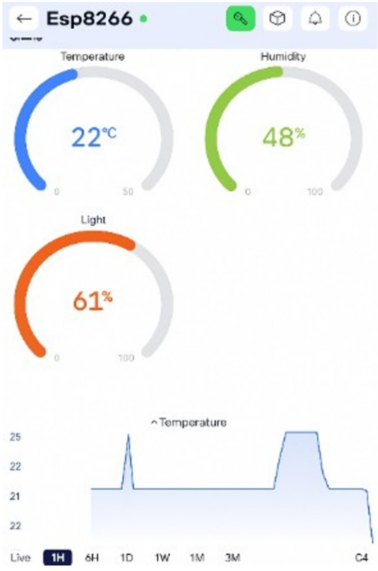

Fig. 1. ESP dashboard.

With the positions of the solar panels carefully chosen based on site circumstances to maximize sunlight absorption, the solar power system was created to provide the laboratory with electricity in an efficient and sustainable manner. A thorough analysis of the lab's energy usage was carried out, which aided in figuring out how many panels and how much battery capacity were needed to store extra energy and guarantee uninterrupted operation. Computers, servers, and other vital lab equipment will soon be run by this system, which will lessen dependency on the conventional electrical grid and help save energy. Additionally, an intelligent energy management system has been incorporated, enabling real-time usage monitoring that enhances efficiency and performance. By carrying out this initiative, the lab will help lower carbon emissions and advance the idea of green computing, setting an example for the use of clean energy in technical and educational settings. Following figure will explain the process [17].

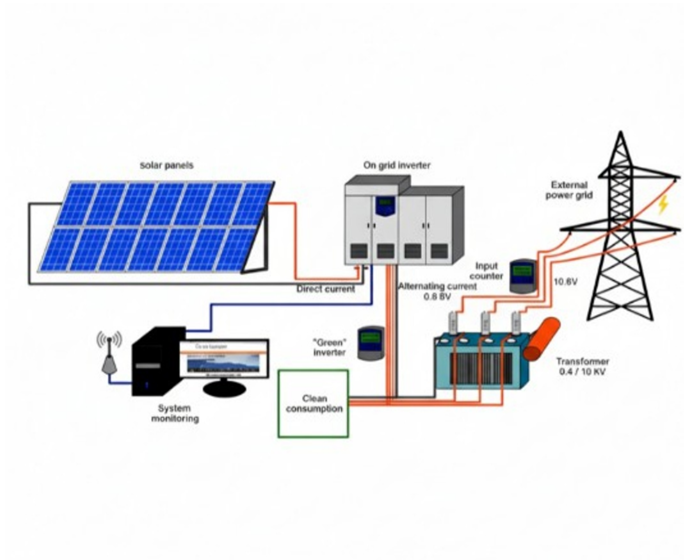

Fig. 2. Solar power plant designing services.

- *Computer Lab Design*

The computer lab at college is intended to consume less energy while performing at a high level. The laboratory has the following equipment:

1. 25 computers: Lenovo ThinkCentre M90a All-in-One.
2. One printer: the Epson Eco Tank ET-4850.
3. TV screen: Samsung QN64Q60TAFXZA, used for educational and demonstrative reasons.
4. Lighting: 10 energy-saving Philips LED bulbs (10w each).
5. To maintain the correct temperature, use the LG S4-W12JA3Q air conditioner.

The lab covers 50 square meters and is meticulously designed to provide a comfortable and efficient working environment. Proper lighting and temperature are used to enhance user comfort and productivity.

- *Operating Systems and Software Used in the Computer Labs at College*

Because it offers a stable environment that works with most academic programs, Windows 10/11 Education or Pro is the ideal platform for operating laboratory equipment. This system offers centralized device management, sophisticated security features, and compatibility for a range of educational and developmental applications. In addition to online browsers like Google Chrome, Mozilla Firefox, and Microsoft Edge, the necessary applications include Microsoft Office 365 or LibreOffice for document editing and presentation creation. Installing antivirus software like Windows Defender, Bitdefender, or Kaspersky is necessary to guarantee device security.

Programmers should have access to integrated development environments (IDEs) that support many programming languages, such Visual Studio Code, Eclipse, and IntelliJ IDEA for Java application development. PyCharm and Anaconda are reliable tools for Python programming, whereas Dev-C++ or Code: Blocks are necessary for C and C++ language learners. In addition to

Microsoft SQL Server for environments that need integration with Microsoft systems, open-source alternatives for database management and instruction include MySQL, MariaDB, or PostgreSQL. Programs for networking and cybersecurity Students can be taught about encryption technologies and safe communication by installing OpenVPN and Wire Guard, which allow them to build and test VPN networks. Software for graphics and design in addition to Blender for 3D creation, the lab requires specialized design applications such Adobe Photoshop and Illustrator for image processing and graphic design. SolidWorks and AutoCAD can be set up for engineering design if the lab is utilized for engineering specializations. Communication apps like Zoom and Microsoft Teams can be used to conduct online meetings and lectures, while e-learning and collaboration tools like Moodle or Google Classroom can be set up to support online education.

- *PV System*

The PVsyst software, one of the most precise and expert tools for assessing and creating solar energy systems, was used to create the solar panels. In order to guarantee the supply of enough and sustainable energy, the design was completed based on the computing lab's energy consumption and operational requirements. In order to maximize solar radiation utilization and achieve high energy production efficiency, the lab's area and geographic position were also considered. This helps to promote the idea of green computing and lessen dependency on conventional energy sources. The following are the tables explaining project and system summary as shown in tables 1and 2, while table 3 shows the general parameters that use in experimental work. It was free horizon the used models were diffuse, transposition, and circumsolar. In addition, table 4 declares the PV array characteristics containing model, operating voltage, total PV power, total inverted power. Besides, Table 5 shows array losses in considering thermal loss factors, and the Loss Fraction reached 2.0 % MPP. Finally, table 6 stated CO2 emission balance in the Libyan country conformed with a figure 3. The following tables show the details for each element.

Table 1 Project summary

		Project summary		
Grid-Connected System		**No 3D scene defined, no shadings**		
PV Filed Orientation		**Near Shadings**	**User's needs**	
Fixed Plane		No Shadings	Unlimited load(grid)	
Tilt/Azimuth	**30/0⁰**			
		System information		
PV Array			**Inverters**	
Nb. Of modules		20 units	Nb. Of units	1 unit
Pnom total		11.10 kWp	Pnom total	10.00
kWac			Pnom ratio	1.110

Table1 presents a summary of PV system that used in the study, it is grid connected configuration alongside total nominal power of **11.10 kWp**, the PV module is 20 units and its title angle is 30°. The PV array is designed as no shading besides no near shading effects. The user's load was defined as unlimited.

Table 2 System Summary

System summary			
Geographical Site	**Situation**		**Project setting**
Benghazi	Latitude	32.11 ^{0}N	Albedo 0.20
Libya	Longitude	20.7 ^{0}E	
	Altitude	14 M	
	Time zone	UTC+2	
Weather data			
Benghazi			
Meteonorm 8.1 (1991-2010), Sat=100% - Synthetic			

Previous table shows both geographical site and weather data-based Benghazi – Libya simulated a solar system under climatic conditions typical of Benghazi, utilizing reliable long-term data. The latitude is 32.11 ^{O}N and it is influencing the optimal panel tilt angle while Longitude is 20.7 ^{0}E and Altitude is 14 M. moreover. Earth's surface albedo reached 0.20 which presents 20% From the terrestrial radiation emitted by the Earth. The data is wholly based on sat images.

Table 3 General Parameters

General parameters			
Grid-Connected System	**No 3D scene defined, no shadings**		
PV Filed Orientation			
Orientation	**Shades configuration**	**Models used**	
Fixed Plane	No3D scene defined	Transposition	Perez
Tilt/Azimuth **30/0^0**		Diffuse	Perez, Meteonom
		Circumsolar	Separate
Horizon	**Near shadings**	**User's needs**	
Free Horizon	No Shadings	Unlimited load (grid)	

Table 3 shows that panels are fixed and not tracking system, it is set in a free zone. he simulation employed the Perez model for both *transposition* and *diffuse irradiation* calculations, combined with Meteonorm synthetic weather data, which enhances the accuracy of irradiance estimation. The circumsolar component was treated separately to better account for diffuse light behaviour under varying sky conditions. The system was simulated under the assumption of an unlimited load (grid connection), meaning that all the generated energy can be utilized or exported to the grid without restriction. These parameters collectively represent optimal environmental and operational conditions for evaluating the system's energy yield and performance ratio.

Table 4 PV array

PV Array Characteristics			
PV module		**Invertor**	
Manufacturer	**Generic**	Manufacturer	**Generic**
Model	JKM-555N-72HL4-BDV	Model	Sunny Boy 10000TL U-208
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	555 Wp	Unit Nom. Power	10.00kWac
Number of PV modules	20 units	Number of Inverters	1 unit
Nominal (STC)	11. 10 kWp	Total Power	10.0 kWac
Modules	2 string x 10 in series	**Operating Voltage**	**300-480 V**
At operating cond. (50^{0}C)			
Pmpp	10.27 kWp	Pnom ratio (DC:AC)	1.11
U mpp	384 V		
I mpp	27 A		
Total PV power		**Total inverter power**	
Nominal (STC)	11 kWp	Total power	10 kWac
Total	20 modules	Number of Inverters	1 unit
Module area	51.7 m^2	Pnom ratio	1.11

Table 4 presents the detailed configuration of the photovoltaic (PV) array and inverter used in this study. The PV field consists of 20 modules (JKM-555N-72HL4-BDV) with a nominal power of 555 Wp each, resulting in a total installed capacity of 11.10 kWp under Standard Test Conditions (STC). The modules are arranged in two parallel strings, each containing ten modules connected in series. At an operating temperature of 50°C, the array delivers a maximum power (Pmpp) of 10.27 kWp, with a voltage (Umpp) of 384 V and a current (Impp) of 27 A. The system uses a Sunny Boy 10000TL U-208 inverter with a rated power of 10.0 kWac, operating within a voltage range of 300–480 V. The DC/AC ratio of 1.11 ensures optimal inverter loading and minimizes conversion losses. The total active area of the PV modules is 51.7 m², providing efficient energy conversion under Benghazi's climatic condition.

Table 5 Array loses regarding PV system

Array losses

Thermal Loss Factor		**DC wiring loss**		**Module Quality**	
Module temperature according to irradiance		Global Array res	234 mΩ	Loss Fraction	-0.8%
Uc (const	20.0 W/m^2K	Loss Fraction	1.5% at STC		
Uv (wind)	0.0 $W/m^2K/m/s$				
Module mismatch losses				**Strings Mismatch loss**	
Loss Fraction	2.0 % at MPP			**Loss Fraction**	**0.1%**

IAM loss factor

0^0	30^0	50^0	60^0	70^0	75^0	80^0	85^0	90^0
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

This table summarizes the critical performance losses within a Photovoltaic (PV) array. The data shows that the designer accounted for significant thermal losses (assuming a factor 20% W/m^2K and neglecting wind cooling), alongside a substantial 2.0% loss due to module mismatch. Conversely, the figures indicate high module quality (-0.8\% quality loss fraction) and negligible losses from DC wiring and string mismatch. The Incidence Angle Modifier (IAM) table confirms that optical reflection becomes the dominant loss factor at oblique sun angles (like sunrise and sunset), where approximately 32% of the incident radiation is lost at an 80^0 angle

Table 6 CO_2 emission balance

CO_2 Emission Balance		
Total		
Generated emissions		
Total:	20.77 tCO_2	
Source: Detailed calculation from table below		
Replaced Emissions		
Total:		526.7 tCO_2
System production:		19.93
Grid Lifecycle Emissions:	881	
Source:	IEA List	
Country:		
System Lifecycle Emissions Details		Libya
Lifetime:	30 years	
Annual degradation:	1.0%	

Item	LCE	Quantity	Subtotal
			[kgCO₂]
Modules	**1713**	**11.1 kWp**	**19011**
Supports	**kgCO2/kWp**	**200 kg**	**1175**
Inverters	**5.88 kgCO2/kg**	**1.00**	582
	582 kgCO2/		

Table 6 indicates that CO_2 emission balance proposed PV system has a highly positive environmental impact in Libya. The total lifecycle carbon footprint of the system (generated from manufacturing and components) is estimated at 20.77 metric tons of CO_2. Conversely, by replacing electricity from the Libyan public grid, which has a high emission factor of 881kg CO_2 /MWh (sourced from the IEA list), the system is expected to avoid the generation of 526.7metric tons of CO_2over its 30-year lifetime. This results in a substantial net environmental savin of approximately 506 tons of CO_2 highlighting the project's effectiveness in mitigating emissions.

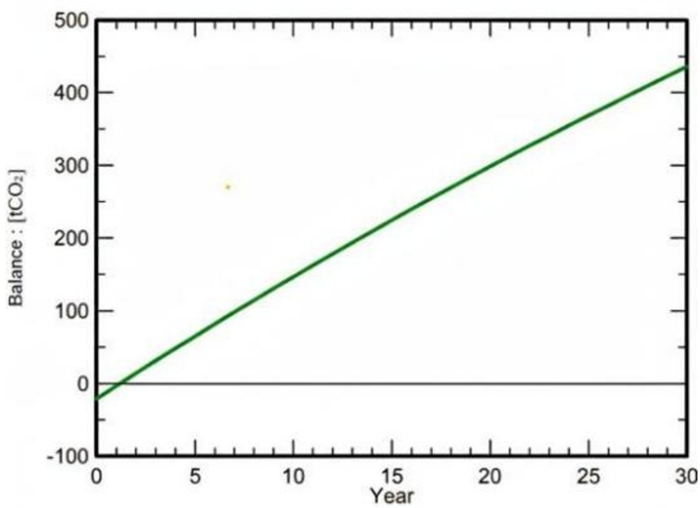

Fig. 3. Saved CO_2 emissions vs time.

The graph visually confirms the project's strong environmental viability. The system reaches carbon neutrality in less than a year, after which it provides significant, sustained CO_2 mitigation by preventing the emission of hundreds of metric tons of carbon dioxide over the subsequent 30 years.

5 Conclusion

The ongoing study presented a comprehensive framework and designed a prototype for labs at university of Benghazi for establishing an environmentally sustainable. A PV consists of 20 units was designed with grid connected system. The aim was to save energy and reduce carbon emissions to save environment from toxic elements. An ESP8266 microcontroller was employed alongside sensors, controlled via the Blynk cloud platform, enables real-time monitoring and significant energy savings. Furthermore, the PVsyst simulation confirms that a solar power system can effectively meet the lab's energy demands, projecting a net reduction of over 500 tCO_2 over its operational lifetime.

The findings declare environmental efficiency of the suggested PV system and successfully achieved reducing carbon emissions in less than one years and continues to save hundreds of tons CO_2 for the environment over the remaining thirty years of its life duration.

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