The Applicability of the Solar Powered Aquaponics Mobile Unit at Sharjah Campus for Sustainable Perspective of Food Security

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Abstract: - By recognizing the limitations of conventional farming methods in meeting the escalating global population and the resulting increased demand for food, this study emphasizes the crucial need for sustainable agriculture techniques. This work focuses on establishing a solar-powered aquaponics system as a sustainable, cost-effective, and ecologically responsible approach to ensure food security in the UAE. This paper describes the implemented aquaponics prototype within the mobile learning unit at the Sharjah Campus of the Higher College of Technology by integrating fish and plant cultivation in a closed-loop system to prioritize water conservation and eliminate reliance on soil, align with United Nations sustainable development goals and promoting sustainable farming practices for robust food production in the UAE. The solar energy system was employed for 6 photovoltaic modules for LED lights and 13 photovoltaic modules for the pumping system, with a total installation area of 50 m^2. It is found that the power requirements are comparatively lower than the vertical setup, which requires 6 photovoltaic modules for the LED and 14 photovoltaic modules for the pumping system. This paper assesses the functional parameters, including electricity consumption by solar panels and water pump energy usage. Furthermore, investigates the impact of fish and plant interactions on water quality and nitrification efficiency, addressing deficiencies in traditional farming and aquaculture. Monthly evaluations reveal favorable conditions, with pH levels of 6.4-7.2, temperatures between 31.8°C and 34.7°C, and ammonia levels at 1 mg.L-1. Aquatic life exhibits an 83% survival rate and a specific growth rate of 3.92% daily.

Key-Words: - aquaponics, renewable energy, vertical installation, solar energy, solar power, photovoltaic.

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1 Introduction

Several hazards to food security, water resources, and the environment have emerged and grown leading to a high demand for technological advances in the energy sector. This is also supported by research showing the exponential growth in power and energy research activities over the last few decades. In parallel, energy demand is also estimated to grow to reach a maximum peak between the years 2016-2040, [1], [2], [3], [4], [5].

Despite the worldwide spread of trends supporting energy conservation, green energy supply, and minimal environmental impact, the production of energy that covers the world's demand remains a difficult challenge. The greatest challenge remains to supply electricity from clean sources including renewable energy that can lead to reducing the usage of fossil fuels, [6], [7], [8], [9], [10].

Renewable energy has the advantage of being able to cover the world's energy demand. It is promising and can limit the dependency on other energy sources such as oil and uranium, as these energy sources are both costly and non-environment friendly. Renewable energy sources provide a competitive alternative to electricity generation and among the various renewable energy sources, solar energy tends to be unlimited and accessible to cover human electrical consumption which has paved the way for great research interests, [11], [12], [13], [14], [15], [16].

As the world's population rises dramatically, so does the need for all kinds of food. Meanwhile, the need for sustainable and creative agriculture techniques is crucial since conventional farming and gardening methods may not be able to fulfill such rising demand. Here, aquaponics technology has come to the fore as a means of raising agricultural output sustainably. Together, fish farming (aquaculture), soilless gardening, and nitrifying bacteria form a self-sustaining ecosystem known as aquaponics, [17], [18]. Essentially it grows protein and carbohydrates together in a symbiotic relationship, drastically reducing the amount of water needed for growing plants. The waste is converted to nutrients for the plants and in turn the plants help filter and clean the water, so it is suitable for the fish. The plants and fish grow in the same water, therefore there is also no need for soil. Soil degradation and desertification are becoming a major issue across areas reliant on farming. Both the conservation of water and non-reliance on soil is potentially a major contributor to addressing sustainable development goals. The water is pushed through several zones of bio-filtration. There is also a delicate balance between water circulation, temperature, quantity, and types of fish and plant species. Furthermore, an indoor LED lighting system is designed for the plants.

Human civilization is at a precipice, our very existence depends on finding innovative, sustainable solutions that enable us, and future generations, to fulfill our needs and wants without compromising the natural environment. Food and in particular agriculture are the most destructive human activity and represent the highest cost to the environment, [19].

For example, here in the UAE, over 90% of our freshwater is used by the agriculture sector. A fully sustainable aquaponics system is a solution, part of a mix of strategies, to enhance farming and agriculture productivity and mitigate the impact on our environment. The attention on aquaponics systems is increasing due to their high efficiency, availability, and lower resource consumption.

Aquaponics is increasingly seen as an important component in solving the issue of food security and establishing sustainable agriculture around the world, [20], especially in developing countries and arid regions, [21], [22]. At its core aquaponics combines the benefits of aquaculture and hydroponics to significantly reduce resource dependence and enhance yields. Using a process of circulating and enriching water in a closed-loop system, aquaponics reduces water usage by more than 90%, [20], [21], [23]. Moreover, there are further opportunities for resource reduction and efficiency by combining innovations in vertical farming, waste management, and renewable energies. Paving the way for a decentralized, sustainable closed-loop urban agriculture sector that will prove to be crucial ingredients in solving many global issues such as food, water and energy security, clean air, and climate change, [24]. In the UAE, an economy heavily dependent on imports, all of these vital issues are echoed louder with the need for self-reliance and a future-proof economy, [25], [26], [27], [28]. Directly addressing a number of the UN and UAE's sustainable development goals.

Aquaponics is a type of bio-integrated structure that blends aquaculture and hydroponics to create a mutually beneficial ecosystem for the growth of aquatic life and plant life. Ammonia, which is produced by fish waste, poses a serious threat to the health of any species living in an aquarium. The symbiotic relationship between plants and nitrifying bacteria stems from the fact that the bacteria can convert ammonia into nitrites and nitrates, both of which are useful plant nutrients. [29], designed a smart aquaponics setup including a planted grow bed and a fish tank which were the main components.

When space and water are in short supply, aquaponics is often favored over conventional farming. By sharing a common water source, plants, and fish could thrive in a hospitable setting that reduced water use significantly. On the other hand, Due to high rates of urbanization, limited available land, and low levels of domestic fish and vegetable production, food security and sustainability are key issues in many countries such as Singapore. Kyaw and Ng, [30], aim to create a sophisticated aquaponics system that can simultaneously support fish farming and plant cultivation. The system used some sensors, actuators, a microcontroller, and a microprocessor to keep tabs on the aquarium's temperature, lighting conditions, and food supply. Therefore, the suggested smart aquaponics system is a viable option for commercial farmers and home gardeners seeking a low-maintenance, cost-effective, and environmentally friendly urban agricultural option. It has been suggested that the Kyaw and Ng project aims to design and create a smart aquaponics system with the potential to combine fish farming with plant cultivation, [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45].

[46], designed a project to train students to think across disciplines while solving problems. As a result, they developed a solar-powered aquaponics setup controlled by an Arduino microprocessor. The aquaponic greenhouse is an integrated system that blends traditional aquaculture with hydroponics. Students can keep tabs on the aquaponics system's functions and use this knowledge to better grasp biological, physical, and chemical phenomena. There are two primary components to aquaponics: the aquaculture system and the hydroponic system. The fish tank and its associated filtration and life support systems stand in for the entire aquaculture infrastructure. Sand, coal, and gravel can be utilized in a conventional three-stage filtering system, or a vortex filter can be employed to collect residue at the filter bowl's base. Additionally, to reduce the negative effects of energy production on the environment, aquaponic greenhouse runs on green power. Students get the opportunity to consolidate their learning across disciplines in a setting like this laboratory, [29], [30], [46].

The above closed-loop type systems can be found in many engineering applications. Consolidating the system and developing its efficiency is very important in many applications that lead to understanding and clarifying the parameters affecting performance. Hence, it is recommended to establish this system to investigate the effective utilization of the applications, [21], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58].

Renewable energy sources are crucial for the development and growth of economies and civilizations. Solar is an alternative energy to generate electricity. The motivation of this research is to operate the system with solar energy. Solar energy is available in great abundance in nature, where we can generate electricity by using photovoltaic solar panels (PV). In this project, the PV technology will be used as an input to all LED lights and pumping systems.

Located in the mobile learning unit at Sharjah Men's Campus, the prototype displays a working aquaponics system that uses 90% water less than conventional agriculture. Furthermore, the system will become fully sustainable when it is operated by solar energy (renewable energy) input and innovations in vertical farming. Investigating and developing these types of cutting-edge solutions will enable us to establish a fully SMART and sustainable aquaponics system. A system that can be scaled and commercialized to establish HCT as an important hub for sustainability in the UAE and the wider region. This type of SMART aquaponics is especially beneficial to the UAE due to significantly lower water usage and a smaller physical and environmental footprint. This system increases efficiency and scale potential to suit commercial applications and to enhance productivity as it uses renewable energy input. of aquaponics. This project proposes to investigate and establish the most optimal agriculture aquaponics system that is operated entirely on renewable energy and delivers efficiencies in waste and water management. Furthermore, this project will be a great opportunity for establishing sustainable practices at Sharjah Campuses and HCT's position as a pioneer in sustainable research. This facility (project) is almost ready for general visits. We explore to utilize this project as a facility for further research. Alternatively, HCT faculty may also incorporate this facility to add value to or enhance their existing courses.

2 The Working Principle of the Aquaponics System and Methods

A working aquaponics system project (Aquaponics System at the Sharjah Sustainability Hub) has been set up as a working prototype that is displayed within an old mobile learning unit (MLU) at the Sharjah Campus currently parked at SJM, close to E block (Mobile Bus Aquaponics system). The aquaponics system is a system of aquaculture in which the waste produced by farmed fish or other aquatic animals supplies nutrients for plants grown hydroponically, which in turn purifies the water. Due to the automatic water recirculating system, aquaponics does not require much monitoring or measuring. Essentially it grows protein and carbohydrates together in a symbiotic relationship. Drastically reducing the amount of water needed for growing plants, [20]. The waste is converted to nutrients for the plants and in turn the plants help filter and clean the water, so it is suitable for the fish. The plants and fish grow in the same water, therefore there is also no need for soil. Soil degradation and desertification are becoming a major issue across areas reliant on farming. Both the conservation of water and non-reliance on soil are potentially major contributors to addressing sustainable development goals, [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82].

On the surface the system is simple, but some sciences are involved in establishing a robust and efficient aquaponic system. For example, the conversion of fish waste (ammonia) into plant food (nitrates) can be complicated. High concentrations of Ammonia or Nitrates can be fatal for fish and plants. The water must be pushed through several zones of bio-filtration, [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102]. Nitrifying bacteria then convert the ammonia into nitrates. There is also a delicate balance between water circulation, temperature, quantity, and types of fish and plant species. Furthermore, a large indoor system reliant on LED lighting does require a substantial amount of energy input. However, this is somewhat balanced by the absence of artificial fertilizers or pesticides. As stated earlier, the challenge of energy input can also be addressed using renewable energy. The issue of scale and variety remains a major issue in the advancement and acceptance of aquaponics as a major force in sustainable development, [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120]. We must also consider that scale may not be a desirable aspiration. As localization gains prominence small-scale facilities in sustainable communities may represent the most viable growth option for aquaponic systems, [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134]. Figure 1 illustrates the diagram (layout) of the aquaponics system working principle. The illustration below shows the current configuration of the system in the mobile bus. It should be noted that this configuration has been changed and evolved many times and, in many phases, as we are working and trying to develop and improve the system and overcome many challenges. The system shown in Figure 1 consists of the following components: The main tank No.1 which is the fish tank with Tilapia fish as expressed in Figure 2.

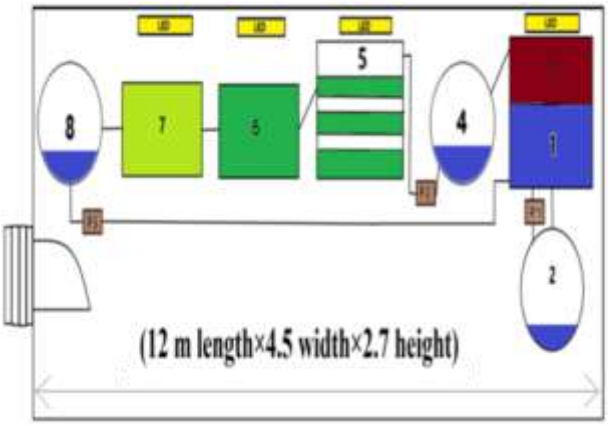

Fig. 1: The aquaponics system diagram setup of the mobile learning unit

Fig. 2: The Fish tank (main tank No. 1)

Tank No. 2 is an experimental bio-filtration system consisting of a mix of media, foams, and filtration materials. This system ensures solid waste does not pass into the system, whilst encouraging the growth of nitrifying bacteria. Tank 3 is the first grow bed, filled with clay hydro ball media, plants in this grow bed also help with filtration. The clay media also houses nitrifying bacteria which help turn ammonia into nitrates. Plants in the tank also help with filtration, as illustrated in Figure 3. Tank No. 4 is a water storage tank, the plants piping system No. 5 which is a net of piping systems with holes distributed over the pipes to grow the plants using the vertical farming principles, as demonstrated in Figure 4. Tanks No. 6 and 7 are floating raft beds as shown in Figure 5. Currently, we are experimenting with an aquatic fern called Azolla (No. 6) and a range of other plants in No. 7. No. 8, which is the sump tank, houses the main pump that pushes water back to the fish tank.

Fig. 3: The plant's filter tank (Tank No. 3)

Fig. 4: The plant piping system (No. 5)

Fig. 5: The floating plant's tank (Tank No. 6)-left and the normal plant's tank (Tank No. 7)-right

A small pump is located within the fish tank that pushes the water into the first bio-filter (Tank, No. 2). Using gravity and a bell, the water is transferred into the first storage tank (No. 4). A small pump pushes the water from this tank into the vertical system, which again using gravity pushes the water through and into the floating rafts, eventually falling into tank No. 8, initiating the cycle again. 6 LED lights are distributed over each plant tank (3, 5, 6, 7) as exhibited in Figure 6, air conditioning system to control the temperature.

The working principle for the system is explained as follows: The first and the main closed loop involves siphoning water from tank No. 3, the plant's filtration tank (grow bed), to tank No. 4, the initial water storage tank. The water level in the plant's filtration tank is managed via a siphon system. This tank contains a single hydroponic substrate material (expanded clay pebbles) for water filtration, on top of which some plants are growing. The fourth water storage tank receives the water after that. The water is then pumped by pump number two to the plants' piping system number five, and to the floating raft reg beds No. 6 and the normal plants tank No. 7 sequentially then the water flows to the sump tank No. 8. This water is fresh and drinkable. The water is pumped from sump tank No. 8 back to the fish tank No. 1 by pump No. 3. The second closed loop is the filtering loop between the fish tank and the biofilter tank No. 3, where the pump No. 1 pushes water from the fish tank to the biofilter tank. Then the water drips to the plant's filter tank (grow bed).

Fig. 6: Photo of the plant LED light system

Aquaponics is a closed, integrated system combining fish framing and plant growing. This closed system uses a tenth of the water traditional framing requires. Fish produce ammonia-rich waste. Too much waste is toxic to the fish, but they can withstand high levels of nitrates. Bacteria are cultured in the grow beds and fish tanks to break ammonia into nitrates. The nitrate-rich water is pumped into a grow bed. The plants absorb nitrates as food. Cleaning the water. Aerated clean water returns to the fish tank.

3 Solar Energy System

The aquaponic system in itself is highly beneficial for soil and water conservation and reserves and is preferred over the conventional farming technique due to its numerous advantages. However, the new trend in research and studies on aquaponic systems is the use of renewable energy for its power requirements. In countries like the UAE, where solar energy is utilized at its core, the work implements the same in the aquaponic prototype setup. The prototype required solar energy for the power requirements of the LED’s and the pumps used. The number of panels needed for the smooth functioning of the complete system was calculated considering all the factors associated with the full setup. The calculations of the solar system were conducted for all lights, and pumps to design and size the correct number of solar panels (PV), batteries, and inverters which are required to operate the system and are explained as follows:

3.1 Solar Power Calculation for LED Lights

Depending on the area the minimum lumens required to cover the area is calculated to be 6300 lumens to illuminate the total space. The 18W LED lights with 1100 lumens are selected. The total lumens are divided over the lumens that the 18W light can produce 6300/1100= 5.7 lights, hence, 8 lights are selected to be installed. Moreover, 6 LED lights are necessary for the plants of the system.

The total appliance energy needed for LED lights is calculated as follows (18 w × 8 lights × 8 hours) + (30 w × 6 lights × 8 hours) = 2592 Wh/day.

The total PV panel's energy per day = 2592 w × 1.3 = 3369.6 Wh/day.

The total energy needed per hour is 3369.6 w/8 = 421.2 watt/hour

The PV sizing 421.2 /80 = 5.265 = We take 6 PV modules

The battery capacity (Ah)= Total energy (3369.6) × 3 days autonomy/0.85% × 0.6 depth of discharge × 12 battery voltage = 1651.7 Ah which is the total Amper-hours required.

Hence, the battery should be rated 12V/1600 Ah for 3 days of autonomy.

If a 100 Ah rated battery is available:

The number of batteries= 1651.7/100 = 16.51 = 17 batteries

The battery charge controller= (6 modules PV × I_{sc} 4.86 A) × 1.25 = 36.45 = 40 A or greater.

Figure 7 illustrates the selected (770×675 mm) Mono-Crystalline PV panel specifications. Figure 8 shows the solar power system.

3.2 Solar Power Calculation for Pumping System

The selected water pump power is 1300 W, and the system needs 3 water pumps. The total watt= 3×1300×12= 46800 Wh/day.

The total PV energy needed = 46800×1.3 = 60840 Wh/day

Total Wp of PV panel capacity needed in one hour (sun hours in UAE is 8 hours) = 60840/8=7605 WP

Number of PV panels = 7605/555 =13.7 then we take 14 modules

So this system should be powered by at least 14 modules of 555 WP solar panels.

Battery capacity= (1300×3) ×3/(0.85×0.6×12) = 1911.76

For 100AH rated battrey= 1911.76/100 = 19.2 then we take 20 batteries.

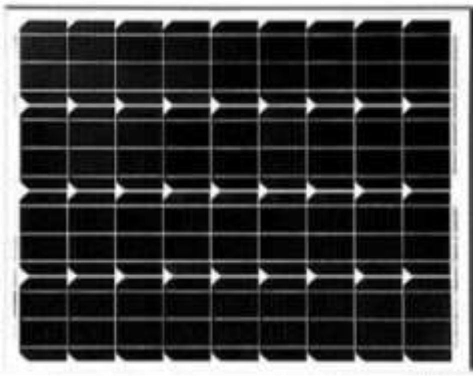

Fig. 7: The (770×675 mm) Mono-Crystalline PV

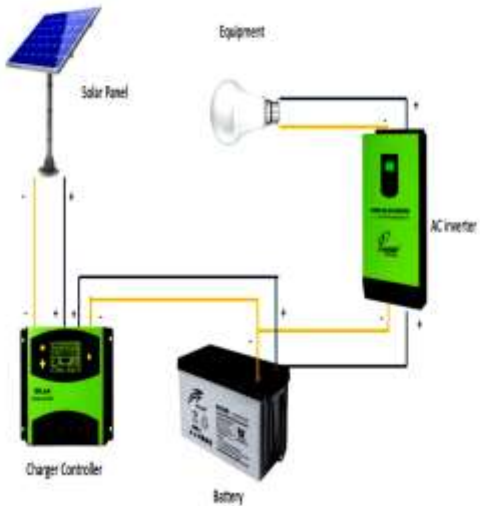

Fig. 8: Solar power system

Sizing the solar panel inverter for the total watts of 3900, where for safety, the solar power inverter should be considered 25%-30% bigger size. Hence, the solar power inverter size should be about 4875 watts or greater. Figure 7 shows the PV panel. Table 1 shows the specifications used for the pumping system. Figure 9 illustrates the PV specifications used for the pumping system.

Fig. 9: The (1134×2278 mm) PV specifications used for the pumping system

Table 1. The (770×675 mm) Mono-Crystalline PV panel specifications for LED Lights

	Electrical Parameters at STC
Model	YS80M-36
Rated Maximum Power at STC	80W
Maximum Power Voltage (V_{mp})	17.8V
Maximum Power Current (Imp)	4.55A
Open Circuit Voltage (V_{oc})	22.4V
Short Circuit Current (I_{sc})	4.86A
Module Efficiency	15-44%
Power Tolerance	0-0.3%
	Mechanical Parameters
Cell Type	Mono-Crystalline 125x125mm (5inch)
Number Of Cells	36 (4x9)
Dimension	770x673x25mm
Weight	6.4kg (approx.)
Glass	3.2mm High Transmission, Low Iron, Tempered Glass
Junction Box	IP65 & IP67 Rated
Output Cable	Length 600mm
Frame	Anodized Aluminum Alloy
Number Of Bypass Diodes	2
Connectors	MC4 Compatible
	Working Conditions
Maximum System Voltage	DC 1000V (IEC)/ 600V (UL)
Operating Temperature	-40^{0}C - +85^{0}C
Maximum Series Fuse	15A
NOCT	45+/-2^{0}C
Application Class	Class A
	Temperature Coefficient
Temperature Coefficient of Pmax	-0.40%/^{0}C
Temperature Coefficient of V_{oc}	-0.30%/^{0}C
Temperature Coefficient of I_{sc}	+0.05%/^{0}C
STC: Irradiance 1000W/m^2, Module Temperature 25^{0}C, Air Mass 1.5	

4 Results and Discussion

The aquaponics system has evolved as an emerging food production technique worldwide. The technique powered by solar energy would multifold the advantages of the techniques while eliminating the disadvantages of setups with far-off power outlets. Hence this study focused on the design of a solar-powered aquaponic system setup within the MLU of the campus. This prototype system acted as a significant opportunity where students (research club and engineering club, capstone students, and energy courses) and faculty members involved helped and supported resolving some of the issues and challenges this facility was facing. The most important development for this project was to operate the system by solar energy where 6 PV modules and 17 batteries are needed for all LED lights (for plants and illumination) with a total area of installation of PV is (2.5×1.5m) = 3.75 m^2. And 13 modules and 20 batteries are required for the pumping system with an area of (9×5m) = 45 m^2. The total area of the installation is 50 m^2. The requirement for all PV needs was calculated and optimal results were analyzed. All these solar panels can be easily installed on the roof of the mobile learning unit as the roof's area is 55 m^2 which is more than the required installation area. With the calculations done for the system at hand, it is evident that the design can be extended for the installation at various scales from as small as ~1m^2 indoor or as big as a large-scale pond structure. The solar performance analysis of the system was carried out including the cost saving and the carbon emission reduction achieved using the designed system. The analysis being vast was conducted as a separate area of study and the major findings are detailed here. The cost saving analysis shows results of return of interest within 1.2 years of installment and therefore, the year further will be profits. Similarly, there will be zero carbon emissions as the entire system is solar-operated. The major inferences obtained in this study were that the value of pH, the temperature, and the ammonia levels of the system were evaluated every month and were estimated to be 6.4-7.2, 31.8-34.7^{0}C and 1mg.L^{-1} respectively. The aquatic lives were found to have a survival rate of 83% with a specific growth rate of 3.92% per day. Better utilization of the space and thereby energy conservation will lead to uninterrupted supply to the aquaponic system thereby helping in much-improved results by maximum ecological management.

5 Future Work and Recommendations

The application development and IOT-enabled system are aspirations for the next stage of this project. Thus, an IOT-enabled facility will be installed and operated for the system's main elements. For example, pumps, tanks, and waterbeds should be WIFI enabled so sensors/switches can be controlled remotely. It would also be great if the application could be developed to manage the system. Also, further improvements to the layout of the system and the control of the water flow rate for the whole system are required to optimize the system's performance. Moreover, designing a renewable system for the air conditioning system is essential in achieving sustainability in the overall energy framework.

6 Conclusions

A working aquaponics system powered by solar energy has been set up within the mobile learning unit (MLU) at the Sharjah Campus. This aquaponics system aims to grow fish and plants together in a closed-loop system. Essentially it grows protein and carbohydrates together in a symbiotic relationship. The main conclusions are summarized as follows: This project will help to establish HCT as a center of excellence for sustainability. Furthermore, it will explore the possibilities of establishing a program in sustainable development or an international center of sustainable research at HCT. Hence, aims to promote and encourage sustainable agricultural practices and ideas to ensure food security in the UAE. The amount of water needed for growing plants in this aquaponics system is drastically reduced by 90%. The plants and fish grow in the same water, therefore there is also no need for soil. The water is pushed through several zones of bio-filtration. The waste is converted to nutrients for the plants and in turn the plants help filter and clean the water to be drinkable and it is suitable for the fish. Solar energy (PV) was designed to operate the system where 6 PV modules and 17 batteries are needed for all LED lights (for plants and illumination). And 14 modules and 20 batteries are required for the pumping system. The area of installation for PV for LED lights is 3.75 m^2. The area for the pumping system is 45 m^2. The total area of the installation is 50 m^2. All these solar panels can be easily installed on the roof of the mobile learning unit as the roof's area is 55 m^2 which is more than the required installation area. The calculations made for the PV requirements bridged the energy requirements of the aquaponic system and hence helped in achieving a sustainable ecological system using renewable energy. This fruitful methodology motivates and enhances the model design to build a larger-scale aquaponic system in a broader spectrum starting within the campus and spreading to the city.

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- Hassan Abdulmouti is the owner of the paper's idea. He contributed to Conceptualization, Methodology, Investigation, and Resources.
- The other authors equally contributed to writing - reviewing & editing the present research.

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