Efficiency For Access Design Challenge

Automated Hydroponic Vertical Farm

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Acknowledgement

We would like to thank Engineers Without Borders UK for arranging such an acitivity to allow people with similar visions in the lines of innovation have their ideas up for consideration and empowering them to actualize their ideas. Together with the EfA Design Challenge team we thank you extensively for your continued support, check-ins, webinars, mentors and knowledge sharing platform that has helped us learn a lot from like minded people and people who have done such activities before us. We thank you for the provision of prototype funding without which our ideas would still be ideas.

We also extend our gratitude to our faculty advisors for the continuous check-ins on where we have reached, critical assesment of our planned activities and feedback on the same as well as their answers to a good amount of questions we have disturbed them with.

Executive Summary

We have designed a low-cost automated and off-grid capable vertical hydroponic unit. This is with the aim of enabling people with no access to farmland and farmers using traditional farming methods a means of obtaining most daily consumed produce in the unforgiving weather trend.

Our prototype design incorporates a 3d printed tower made up of 4 modular fit-in parts that hold the plants and allow water-nutrient mixture to pass through the roots. The water-nutrient mixture is pumped to the tower top from a reservoir at the bottom of the tower.

Each tower part holds 5 plants allowing one to plant 20 plants on a space of a square meter. A simple automated watering system has been incorporated which also allows remote monitoring and control. The product can tap from already existing solar setups due to its low power consumption.

Contents

Introduction

Problem Statement

The current weather trend in Kenya is changing, changing such that our traditional farming practices can't keep up in obtaining enough crop for the population. As a rain-fed economy, Kenya relies almost entirely on produce from small scale farmers who happen to be the most affected by the weather trend [1] (Deutsche Welle, 2022).

Food insecurity brought about by drought and floods has led to:

- Starvation
- Increase in cost of living (stemming from the rise in price of maize flour which is our staple food)
- Resort to human labour in tilling land due to increase in cost of living (further decreasing produce)
- Insecurity(crime) due to increase in cost of living among other challenges.

Current efforts by the government include building huge dams and the current unbanning of GMO produce which will either take time or have unknown consequences thereafter.

Locally available hydroponic solutions still require an amount of space and investment, lack well setup water reuse systems and focus more on fodder than human intended produce.

Project Aims

Our project aims to allow growth of most daily consumed produce such as most vegetables(tomatoes, cabbage, spinach, kale, cucumber, etc) and legumes(beans, peas) in a small space with minimal water consumption and supervision.

This servers to easen the reliance on land farming, easen the reliance on rain as well as allow farming of the same amount of produce or more in smaller spaces and at a low cost.

Of What Significance is Our Aim?

The following are statistics on area harvested, yield and production quantity of daily consumed vegetables and legumes in Kenya from FAO [2] (FAO, 2022):

Produce	Area Harvested (ha)	Yield (hg/ha)	Production (tonnes)	Value Type
Beans, dry	1171869	5683	666000	Official
Broad beans and horse beans, green	576	53083	3057.56	Imputed

Cabbages	31426	349995	1099882	Official
Cow peas, dry	235734	10616	250260	Official
Other beans, green	3922	115587	45331.4	Estimated
Peas	9582	75759	72593.24	Imputed
Spinach	10894	167320	182285.9	Official
Tomatoes	29629	236996	702205.1	Official
Total	1493632	1015039	3021615.2	

We can see a total yield of about 10kg/m^2, from traditional methods of farming.

This can be greatly increased by using hydroponic vertical towers. But by how much?

Here is an example from our team lead family's backyard space:

Here are 70 kale plants occupying an area of $13m^2$. Using the hydroponic vertical towers with an estimated plant capacity of 20 plants per tower which occupies $1m^2$, we can see for the same amount of space 260 kale plants could be planted. This is a yield increase of close to 4 times of the displayed traditional method.

Adding water savings of up to 90% of water used in traditional methods[4] (Jr., 2014), minimal growth duration and labour, we can see such a system for the target traditional farmer and or urban settler will be a good amount of benefit.

Innovation

How Efficient is the Design

Traditional Farming System	Vertical Hydroponic Farm
Requires land	Minimal land requirement
Requires a lot of labour	Minimal labour requirement
Requires a lot of water	Minimal water requirement
Subject to environmental risks such as climate, pests, animal encroachment	Minimal environmental risks
Can be costly due to use of pesticides and other inputs	Minimal cost involved in production
Requires land preparation	No land preparation required
Produce takes relatively longer time to obtain	Short amount of time to obtain produce
Due to soil fertility this method cannot support growth of multiple variety of crops	Can reliably grow multiple variety of crops

SWOT Analysis

Strengths: Many advantages as above

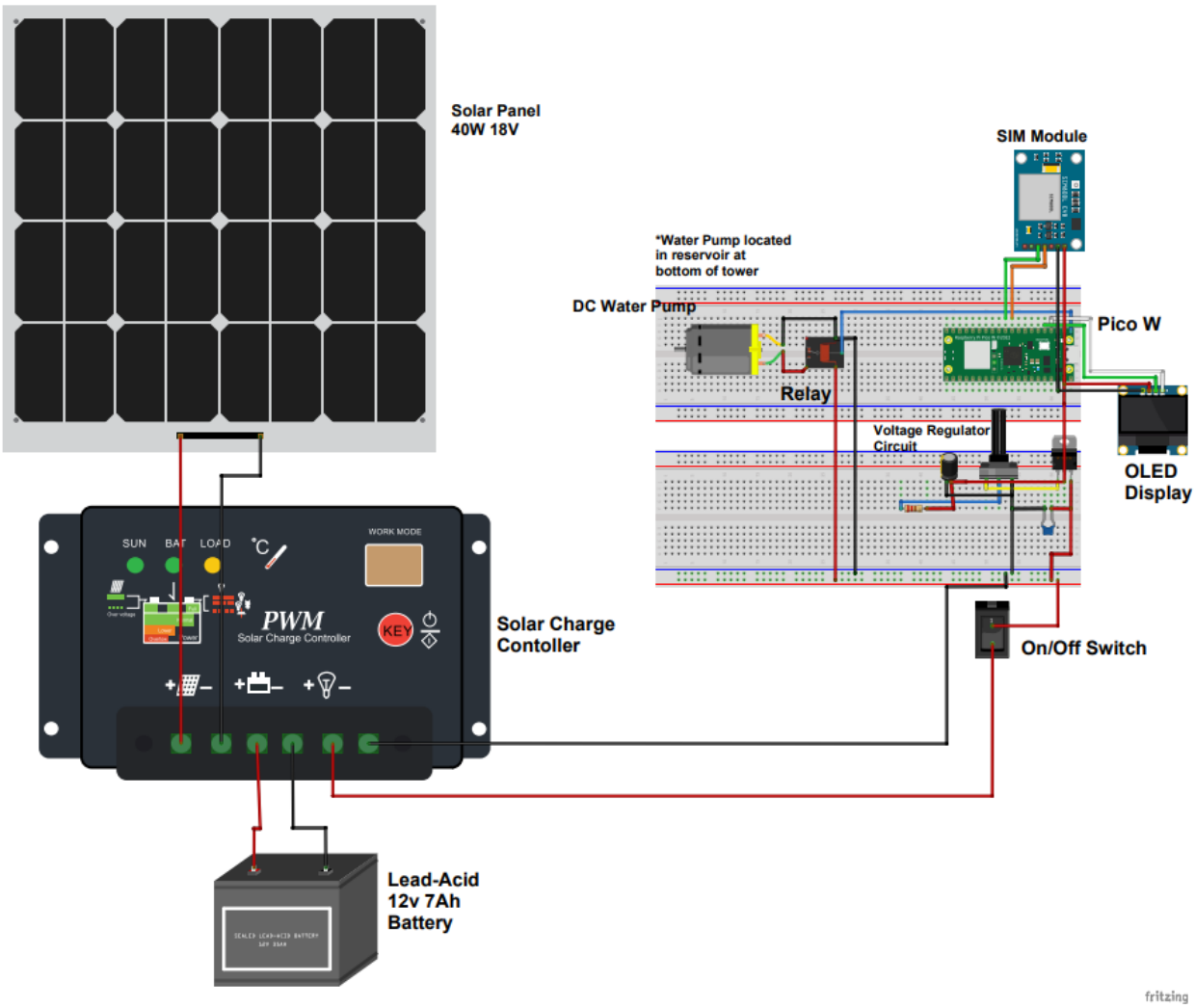
Weaknesses: Cannot grow root tubers

Opportunities: Can be adopted by both rural area farmers and urban settlers

Threats: GMO produce

Project Design and Working

Below is the circuit diagram of the project:



The solar panel will harvest energy from the sun. Harvested power will be used to charge the battery for use in the night and during days with minimal sunlight(which is rare in Kenya, [8] (World Bank Group, 2019)). Harvested power will also use to power the load. Switching the solar panel from charging the battery to powering the load as well as the battery from a charging state to powering the load will be handled by the solar charge controller.

The Raspberry Pi Pico W microcontroller unit(MCU) will be powering on and off the DC water pump at preset intervals just like a timer. The Pico W country location will be set by the user of the product for time synchronisation.

Besides displaying tower data on the OLED, the Pico W will use the SIM module, of which the user will provide a SIM card, to respond with tower data remotely when asked by a user through SMS.

For people having an internet connection, the Pico W will allow the user of the tower to integrate it with a MQTT client to be able to see tower data online. This is ideal for someone using multiple towers and wants to monitor each tower in an efficient manner while storing tower data for future analysis.

Tower data will entail:

- The current state of the water pump, on or off
- Battery and solar panel information, i.e percentage, solar radiation etc.
- Other information logged from the solar charge controller deemed useful.

Production Cost

From the prototype that we wish to implement, majority of the cost goes to the 3D printing filament used to build the structure. This goes for about $28.67 per roll. Assuming a minimum of two rolls will be used this can be about $57.34 for the tower alone.

Including the water reservoir and required electrical components this is an additional cost of about $50 bringing an estimated production cost of $107.34 without including the solar panel, battery and charge controller.

Adding these will bring the total product cost to about $150.

This cost can be further reduced by contracting custom pvc manufacturers on tower parts and miniaturising the electronic components to a printed circuit board (PCB).

Usability

Owing to the simple installation of parts and minimal labour requirement this product can be used by men, women, people with disabilities and children thus leaving no one behind.

Since electricity in operation will be in the order of 12V this poses minimal risk of use to people in households.

Products will be issued with manuals regarding use, particularly on nutrient to water mixture ratios and dates of switching to different type of nutrient, which will come with the product.

Modular nature of product allows for easy replacement of damaged parts in case it happens

Product usage benefits

For people farming using these towers in urban settlements, they will be able to:

- Obtain crop with minimal collusion in terms of:

    - Hygiene of produce seller's workspace. This is because farm produce in towns is mostly sold out in the open where it is polluted[5] (Media Max Network Kenya, 2020).
    - Long storage times and handling process from producer to seller.
- Avoid health problems related to buying less quality produce
- Minimise on food cost involved.

For traditional farmers who are also produce sellers, they will be able to:

- Reduce on labour and other costs involved in food production thus increasing profit margins.
- Meet market demand.
- Free up land for planting other crop that cannot be grown by the tower.
- Increase biodiversity of land.

The product is ideal for:

- Farmers using traditional methods of farming, particularly vegetable growers such as the common "mama mboga"[6] (Rayankobz, 2017).
- Urban settlers and people with small spaces interested in farming their own produce but lack farming land.
- Apartment owners with flat rooftop spaces or any idle spaces aiming to promote food security for tenants.

Environmental Impact

Traditional farming methods have a lot of negative environmental impacts that come along with it including carbon emmissions from farm machinery, pesticides, fertilisers, water wastage and produce transportations.

Putting more land under vertical hydroponic towers will help in curbing emmisions, reducing water wastage by farms and in reducing produce wastage experienced during harvesting of produce.

Social Impact

A general increase in quality of health is expected with increased use of such a product.

Ability to farm in small spaces is likely to bring income opportunities for people in urban settlements.

Increase in food security will reduce cost of living and reduce insecurity.

There will be more focus on water harvesting and storage as people aim to store the little extra amont of water required for their towers.

Sustainable Development Goals

In respect to Sustainable Development Goal 7 [7] (UNEP, 2023) which is ensuring access to affordable and clean energy, our project primarily works towards sector 7.3 which is to double the rate of improvement in energy efficiency. Water and nutrients from the earth are forms of energy and if we improve on how efficient we use land and water we are thus hitting towards the goal. Reducing on produce wastage also improves on energy efficiency as little is going to waste.

In extension our project works towards meeting SDG 1(no poverty), 2(no hunger), 3(good health and well being) and 12(Responsible consumption and production) primarily.

Marketing and Scalability

Marketing such a product will involve:

- Reaching out to agricultural research institutes which regularly offer training to farmers. This will be key in reaching out to people in rural areas.
- Creating social media pages on popular social media platforms to create awareness and to reach out to potential buyers on a constant basis.
- Creating a website to allow interested individuals to review and or purchase our products.

Subsequent word of mouth marketing will rely on how well the product works.

Working closely with every customer who purchases our products to ensure they obtain the expected results we promise them will also be a key endeavour.

Offering directive videos on youtube on setup of the product and operation as well as answers to frequently asked questions will also be important for urban settlers particularly.

Offering on-site and off-site(at customer's location) training at a small fee will also have a good impact in acting as a source of income as well as promoting confidence of customers in our product.

But the question is how do we get the product in people's hands?

How do we get the product in people's hands?

Needless to say $150 is a lot of money considering the average wage of a low income earner is about $3 a day[1] (Deutsche Welle, 2022).

A better approach is to involve people of low income through the "nyumba kumi" groups which are already in place and which have proven to enable people pool their resources to keep costs manageable for each individual member[3] (Grind, 2021). This will also make it easier for the people to obtain financing from institutions such as banks.

For middle income earners, we can make arrangements with banks to enable the bank pay part of the product cost for the customer. Further payments will be up to the customer and the bank.

Using credit systems already in place, such as banks' credit system, is a safer option as the banks already have customer credit information thus any finance issued is based on customer's credit rating.

Working with apartment owners in setting aside space to plant and sell to tenants is another niche that can really enable people benefit from the farm produce without having to purchase the product themselves.

Scalability

Due to the modular nature of such a product, scalability is a relatively smooth process considering the right manufacturing process is obtained regarding building the structure of the tower.

The right manufacturing process will realise the many such structures in a short amount of time and minimal amount of expenditure.

3D printing is ideal for testing different designs of the tower but working with pvc manufacturers will make scalability possible.

Modularity of the product also allows minimal space occupation during transportation to different locations thus more such products can fit in the transporting means used.

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8. World Bank Group. (2019, October 1). *Global Solar Atlas.* Retrieved from Global Solar Atlas: https://globalsolaratlas.info/download/kenya

Appendices

Prototype Fund Application Equipment List

Item Number	Item Description	Link to item/quote where appropriate	Quantity	Unit Cost	Cost
1	Ender-3 V2 Neo 3D Printer	https://store.creality.com/products/ender-3-v2-neo-3d-printer?spm=..collection_6441e458-3e77-43ed-baf5-2671b3222c52.albums_1.1&spm_prev=..product_3b800a4d-f62b-4ceb-980e-a75d007c37d8.header_1.1	1	$299.00	$299.00
2	1.75mm 1Kg White PETG Filament	https://www.pixelelectric.com/3d-printer-cnc-parts/filaments/petg/1-75mm-1kg-white-petg-filament/	5	28.67	143.35

3	JT-180 12V DC Water Pump 350L/H Submersible Pump	https://www.pixelelectric.com/more-categories/other-accessories/liquid-pumps/jt-180-12v-dc-water-pump-350l-h-submersible-pump/	1	15.09	15.09
4	Bucket 20L	https://copia.co.ke/product/star-paint-bucket-20l-green/	1	1.51	1.51
5	Nutrient Solution A&B 1kg	https://www.hydroponicsafrica.org/	2	7.54	15.08
6	Seedling Tray	https://jiji.co.ke/nairobi-central/farm-machinery-equipment/seedling-tray-Cvl2HEcMDksGsmdMOU48mD5g.html	2	0.98	1.96
7	Net Cups	https://jiji.co.ke/nairobi-central/farm-machinery-equipment/hydroponic-net-pots-for-vegetable-and-flower-growing-93S37dwtZacrNYgclWyqHhm3.html	20	0.23	4.6
8	Rock wool pods set 1 m x 30cm	https://jiji.co.ke/nairobi-central/feeds-supplements-seeds/rockwool-for-hydroponic-farming-soilless-potting-medium-oOKrnkT5OQeJkf3WkbyIvkup.html	1	7.17	7.17
9	Solar Panel 40W 18V Monocrystalline	https://www.pixelelectric.com/electronic-modules/miscellaneous-modules/solar-panel/40w-18v-monocrystalline-solar-panel/	1	28.67	28.67
10	Solar Battery - Lead Acid	https://www.pixelelectric.com/more-categories/lead-acid-battery-12v-7ah/	1	11.32	11.32

	Battery - 12V 7Ah				
11	20A LCD Dual USB Solar Charge Controller	https://www.pixelelectric.com/electronic-modules/miscellaneous-modules/solar-panel/20a-lcd-dual-usb-solar-charge-controller/	1	11.32	11.32
12	Raspberry Pi Pico WMCU	https://shop.ivyliam.com/product/pi-picow/	2	9.05	18.1
13	Sim900 Mini V4.0 Wireless Data Transmission Module Gsm Gprs Board Kit W/antenna C83	https://askelectronics.co.ke/product/sim900-mini-v4-0-wireless-data-transmission-module-gsm-gprs-board-kit-w-antenna-c83/	1	15.09	15.09
14	5V 4 CH OMRON SSR Solid Relay Module DC-DC	https://www.pixelelectric.com/electronic-modules/miscellaneous-modules/relay-switch/5v-4-ch-omron-ssr-solid-relay-module/	1	7.54	7.54

15	LM2596HVS-ADJ Step-down 5V regulator	https://www.pixelelectric.com/more-categories/electronic-components/passive-components/transistor-mosfet/lm2596hvs-adj-step-down-5v-regulator/	2	0.75	1.5
16	Schottky Diode 1N5	https://www.pixelelectric.com/electronic-components/passive-components/diode/schottky-diode-1n4-1n5-uf4-fr2-rl2/	2	0.15	0.3
17	Inductor 68uH	https://store.nerokas.co.ke/index.php?route=product/product&product_id=890&search=Inductor&description=true	2	0.19	0.38
18	Resistor 1kohm	https://www.pixelelectric.com/more-categories/electronic-components/passive-components/resistor/resistor-1-120m-ohm-1-4w-5/	2	0.02	0.04
19	Potentiometer 10kohm	https://www.pixelelectric.com/more-categories/electronic-components/passive-components/potentiometer/trimpot-potentiometer-variable-resistor-500r-1m/	2	0.08	0.16
20	Capacitor 470 uF	https://www.pixelelectric.com/electronic-components/passive-components/capacitor/0-22uf-2200uf-radial-electrolytic-capacitor/	2	0.3	0.6
21	Capacitor 220uF	https://www.pixelelectric.com/electronic-components/passive-components/capacitor/0-22uf-2200uf-radial-electrolytic-capacitor/	2	0.3	0.6
22	Jumper wires 40pcs set	https://www.pixelelectric.com/instruments-tools/wire-and-cables/cables/dupont-jumper-cable/65pcs-jump-wire-cables-male-to-male/	2	1.13	2.26
23	Breadboard	https://www.pixelelectric.com/instruments-tools/wire-and-cables/bread-pcb-board-copper-clad/breadboard-mb102-crystal/	2	1.51	3.02
24	Soldering wire 1 roll	https://www.pixelelectric.com/instruments-tools/tools/soldering-tools-kits/1-0mm-100g-rosin-core-solder-63-37wire/	1	5.66	5.66

25	Soldering gun 60w	https://www.pixelelectric.com/instruments-tools/tools/soldering-tools-kits/60w-220v-soldering-iron-adjustable-temperature/	1	6.04	6.04
26	Soldering gun stand	https://www.pixelelectric.com/instruments-tools/tools/soldering-tools-kits/soldering-iron-stand/	1	1.89	1.89
27	Perf-board	https://www.pixelelectric.com/instruments-tools/wire-and-cables/bread-pcb-board-copper-clad/veroboard-stripboard-6-5cm-x-14-5cm/	2	0.38	0.76
28	Single Core Wire 1m	https://www.pixelelectric.com/instruments-tools/wire-and-cables/bread-pcb-board-copper-clad/veroboard-stripboard-6-5cm-x-14-5cm/	5	0.62	3.1
29	Analog pH Sensor / Meter Kit	https://www.pixelelectric.com/sensors/load-pressure-flow-vibration/water-tds-ph-flow-level-sensor/analog-ph-sensor-meter-kit/	1	22.63	22.63
30	1M PVC Hose Pipe for Pumps	https://www.pixelelectric.com/more-categories/other-accessories/liquid-pumps/1m-pvc-hose-pipe-for-pumps/	2	0.45	0.9
31	Spinach Seeds 50g	https://www.simlaw.co.ke//product-details/858/11204	1	1.06	1.06
32	Kale Seeds	https://www.simlaw.co.ke//product-details/602/159	1	1.55	1.55
33	Shipping Cost and Customs for 10kg 3D printer	https://kentexcargo.com/	10	20	200

34	Currency Variations and Transaction costs from EFA team to University to Us	N/A	1	200	200
				Total	$1032.25

Prototyping

We are quite ready to work on the project to completion if we are granted prototyping, which we will really appreciate. There is a lot of unkown variables that can't be well estimated such as growth period of crop, produce to seed ratio of different types of plants among others. We are looking toward collection of such data to offer better numeric estimates regarding the project as a whole. Thank you.