

College of Engineering
Electrical Engineering Department
EE 492 - Capstone Project 2
2023-2024 - Spring Semester



Capstone Project II

DESIGN AND IMPLEMENTATION OF A FLOATING PV POWER PLANT FOR MADINAH REGION

By:

Hamza Alashi

ID: 4010339

Marwan Bitar

ID: 4110259

Under the Supervision of:

Dr. Hadeed Sher

May 16 , 2024

Outlines

01 | Introduction

02 | Literature Analysis

03 | Project Design

04 | Experimentation & Implementation

05 | Results & Discussion

06 | Conclusion

| 01 |

INTRODUCTION

Problem Statement

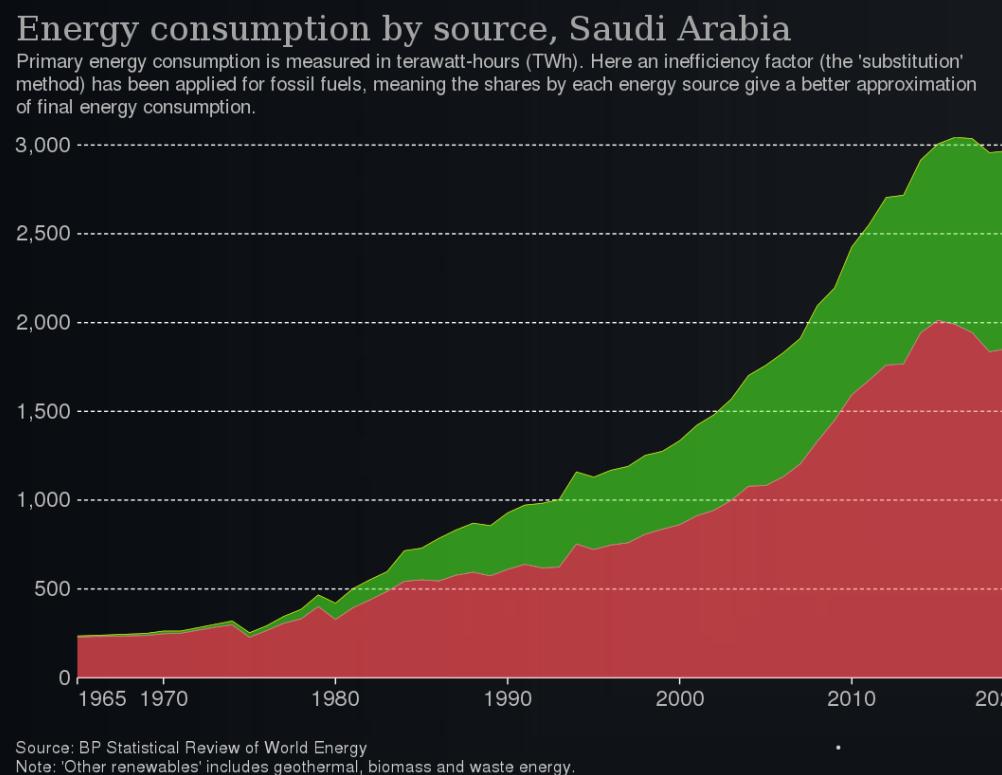
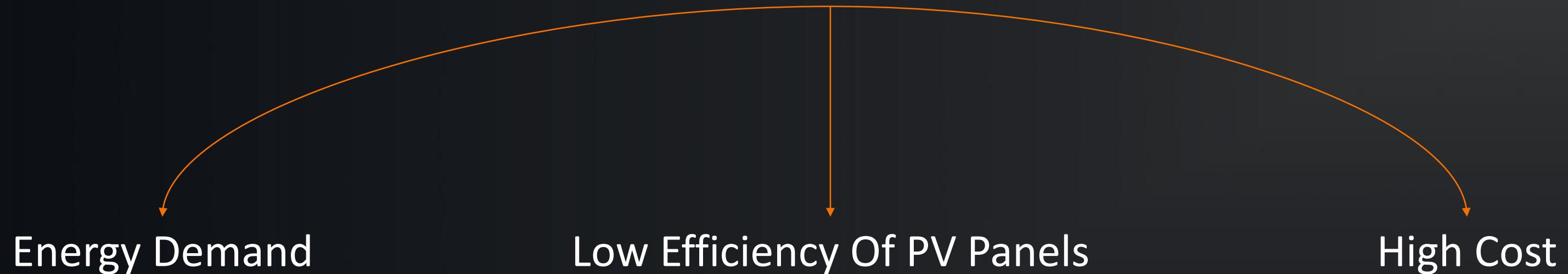


Figure 1

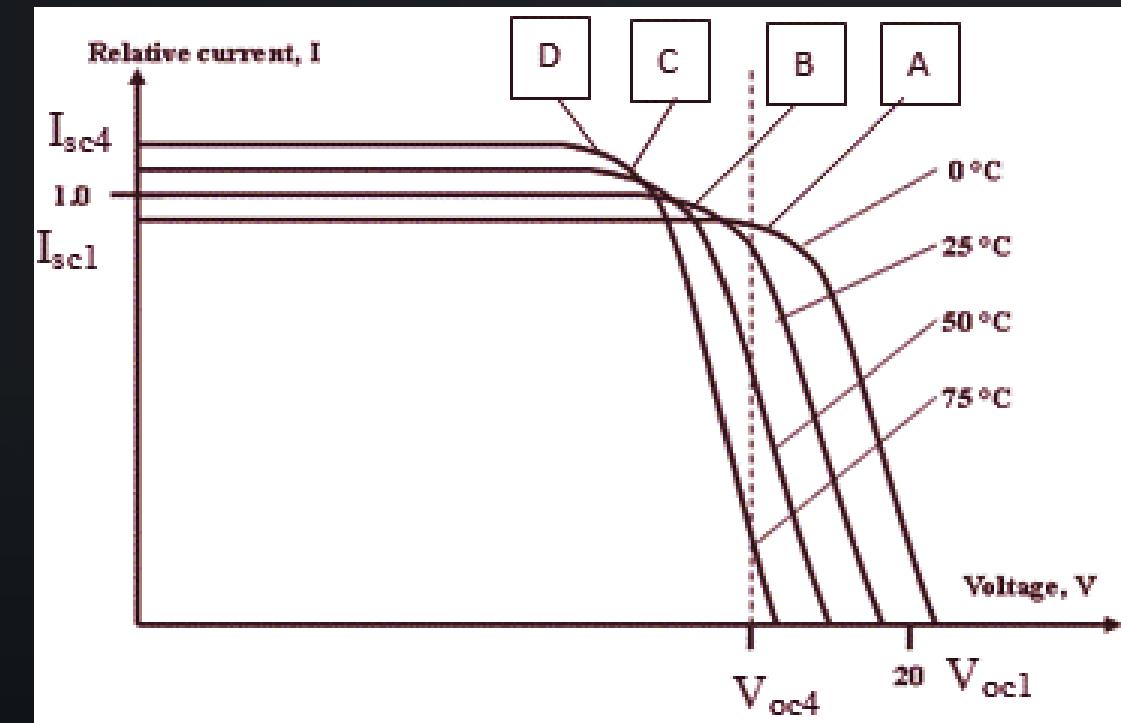


Figure 2

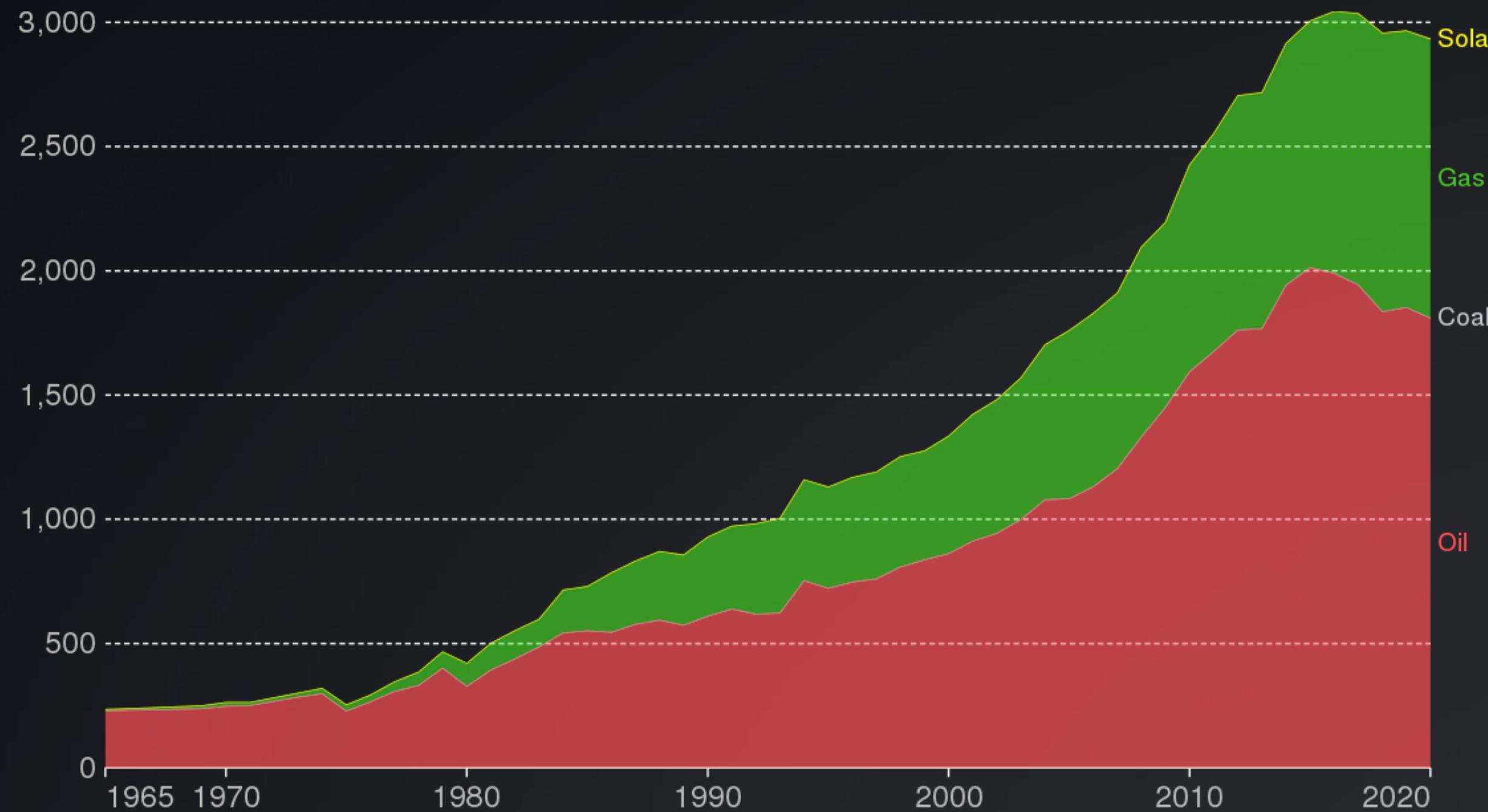


Figure 3

Energy consumption by source, Saudi Arabia

Our World
in Data

Primary energy consumption is measured in terawatt-hours (TWh). Here an inefficiency factor (the 'substitution' method) has been applied for fossil fuels, meaning the shares by each energy source give a better approximation of final energy consumption.



Source: BP Statistical Review of World Energy

Note: 'Other renewables' includes geothermal, biomass and waste energy.

Figure 1. Energy Demand

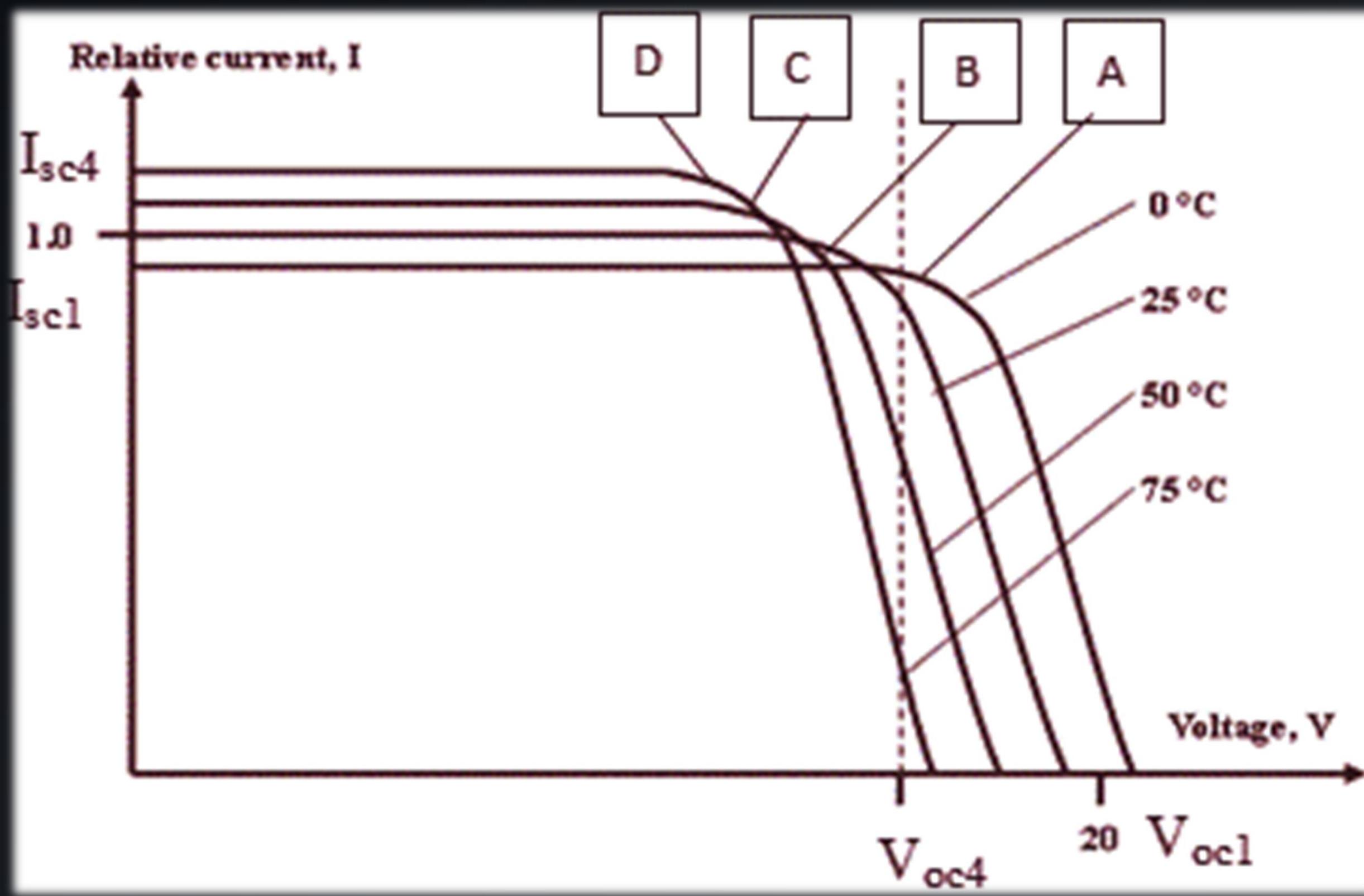


Figure 2. Low Efficiency Of PV Panels



Figure 3. High Cost

— Current Methods (PV Systems) —



Figure 4. On Land



Figure 5. On Rooftop

Proposed Solution

Design and Implementation
of a Floating PV Power
Plant for Madinah Region
(Al-Aqoul Lake)

Objectives:

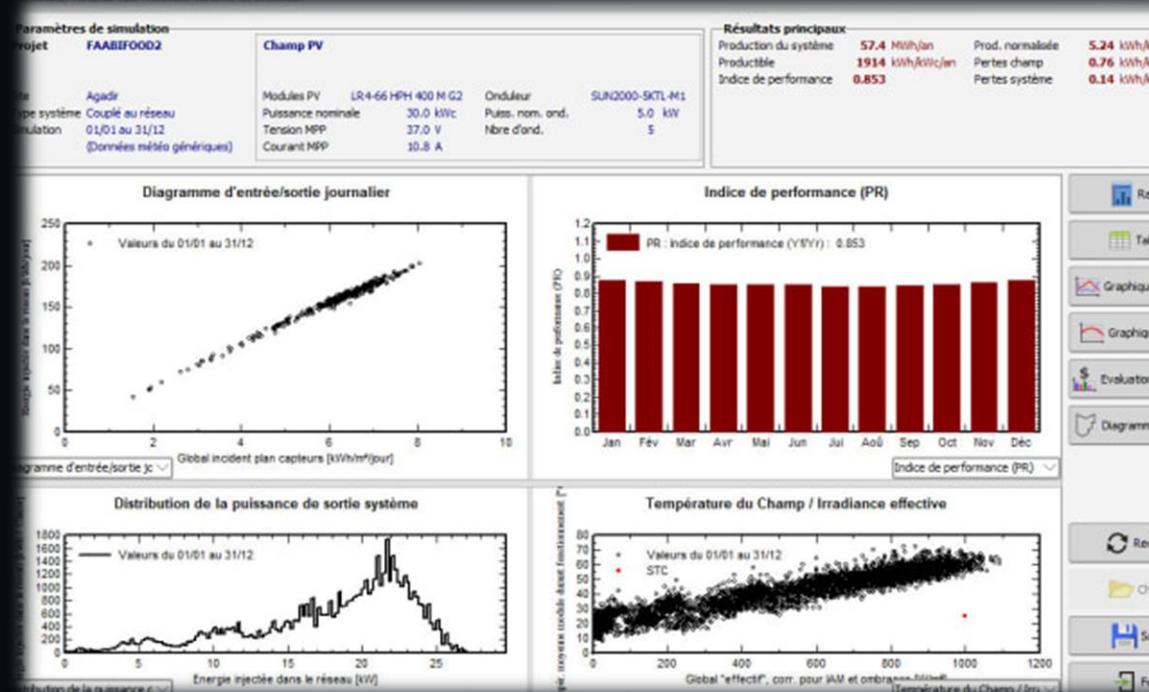
1. Developing Renewable Source
2. Environmental and Economical Advances



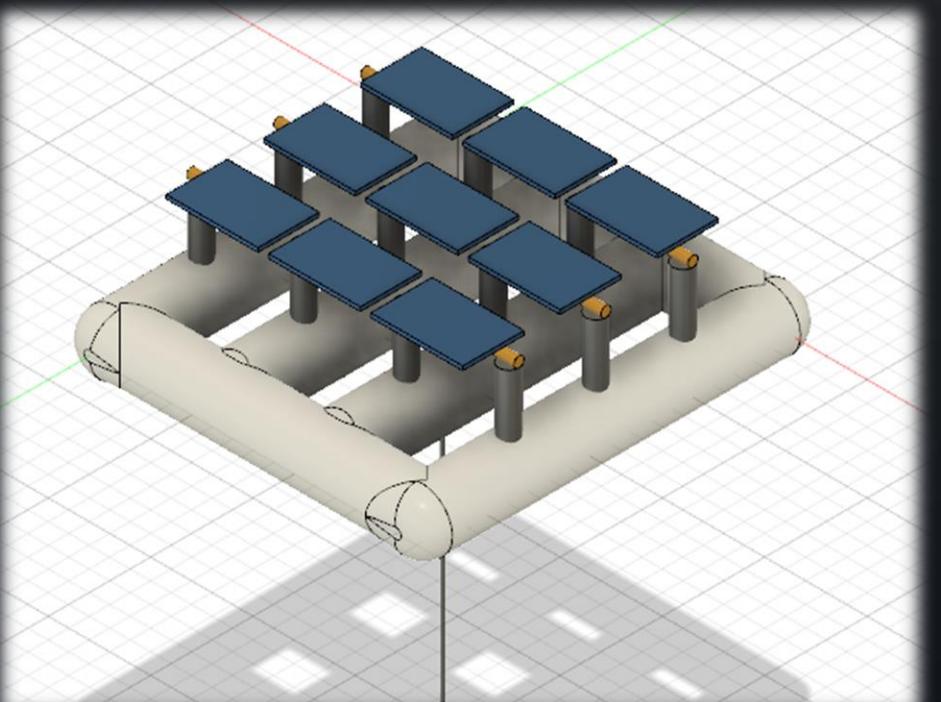
Figure 6. FPV Power Plant

Deliverables

Mega FPV Power
Plant Simulation



Prototype Construction



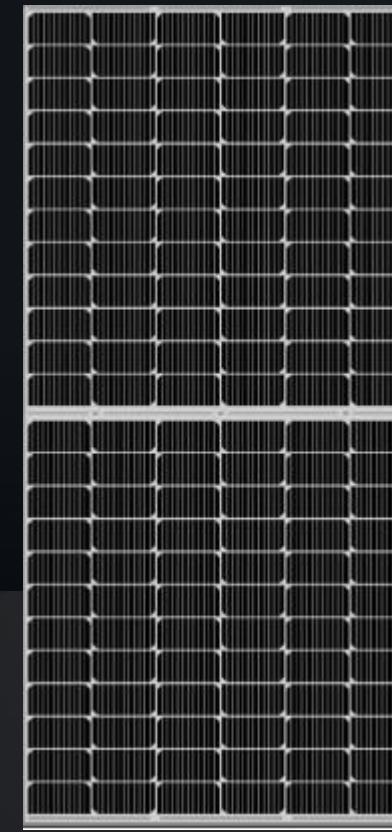
Detailed Financial
Analysis



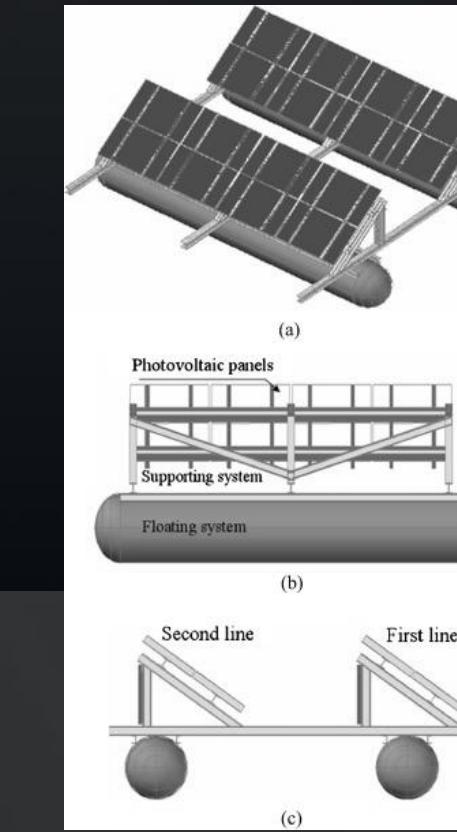
| 02 |

Literature Analysis

Design Parameters & Specifications



Panel Type
and Efficiency



Floating System
Design

Components	Qty	Unit Cost GH¢	Cost GH¢
Bulbs	1	1	1
Diodes, Resistor, Capacitor, Led	1	1	30
Transformer	2	5	10
Crystal	1	2.50	2.50
Relay	2	10	20
Construction board	1	1	1
Lamp holder	1	1.50	1.50
Photocell	1	20	20
Screws	1 box	2	2
(At mega 328P)	1	20	20
UPS	1	110	110
Arduino Uno	1	80	100
Consultation	Once	100	100
13 amp Plug	2	1.50	3
Transportation			40
Communication	10	2.0	20
Mica case	1	50	50
Cable	3 yards	3	9
Rechargeable Batteries	2	20	40
Internet Bundle	1 Month	30	30

Electrical
Layout

Panel Type and Efficiency

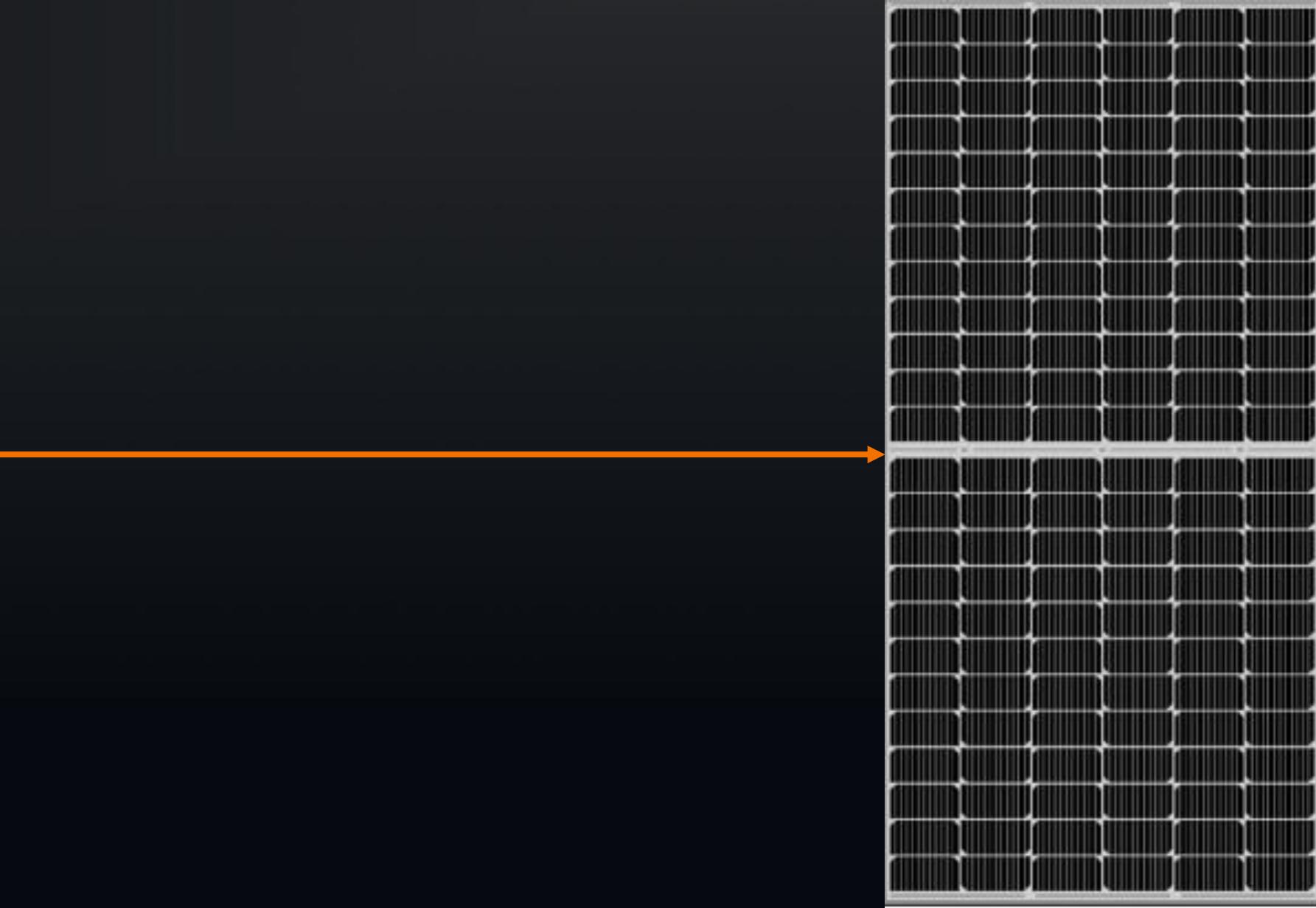
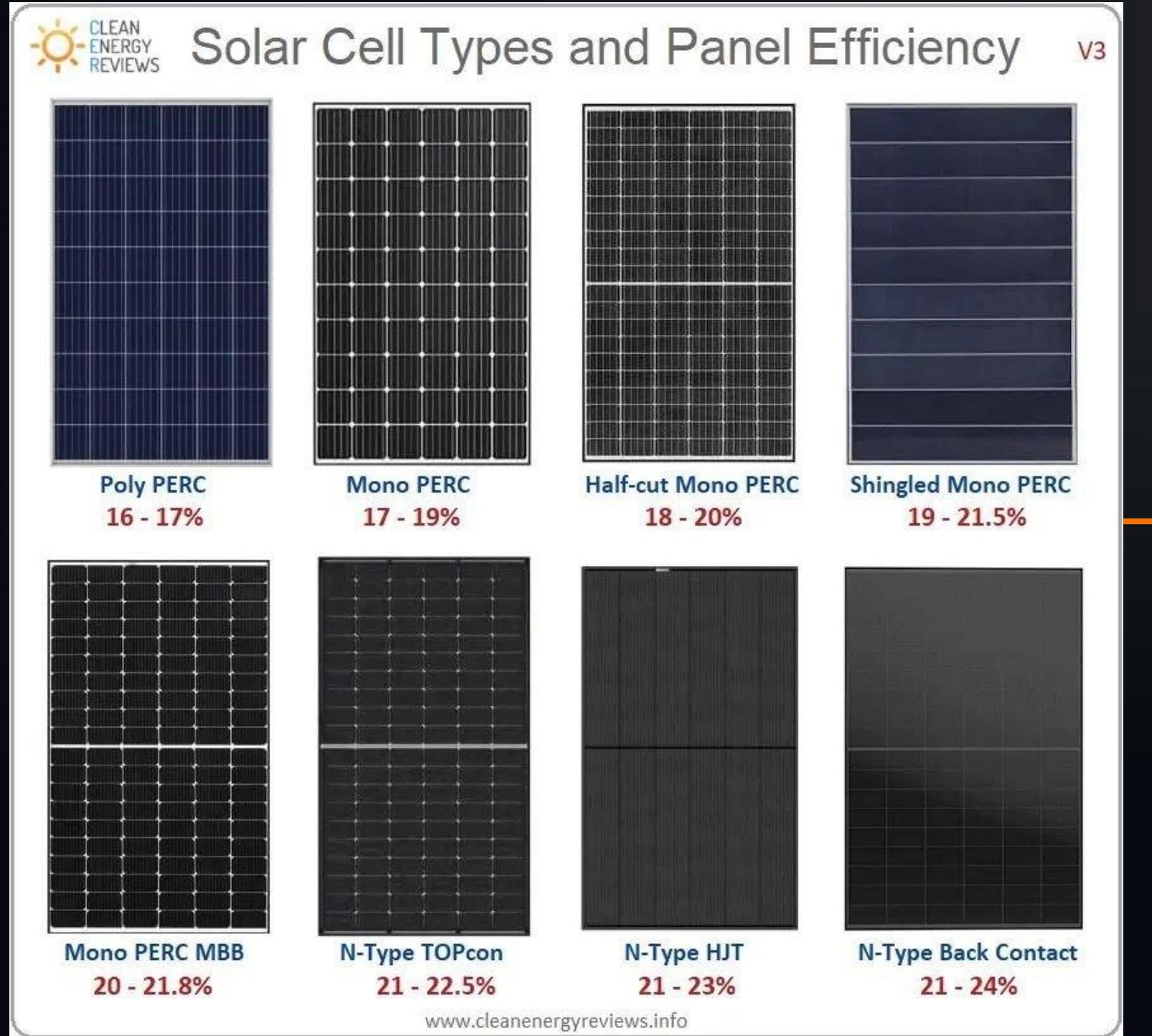


Figure 9. JA Solar 545W Mono PERC MBB Panel

Source:

A. Amer, H. Attar, S. As'ad, S. Alsaqoor, I. Colak, A. Alahmer, M. Alali, G. Borowski, M. Hmada, and A. Solyman, "Floating Photovoltaics: Assessing the Potential Advantages and Challenges of Harnessing Solar Energy on Water Bodies," Journal of Ecological Engineering, vol. 24, no. 10, pp. 324–339, Aug. 2023. [Online]. Available: <https://doi.org/10.12911/22998993/170917>

Floating System Design

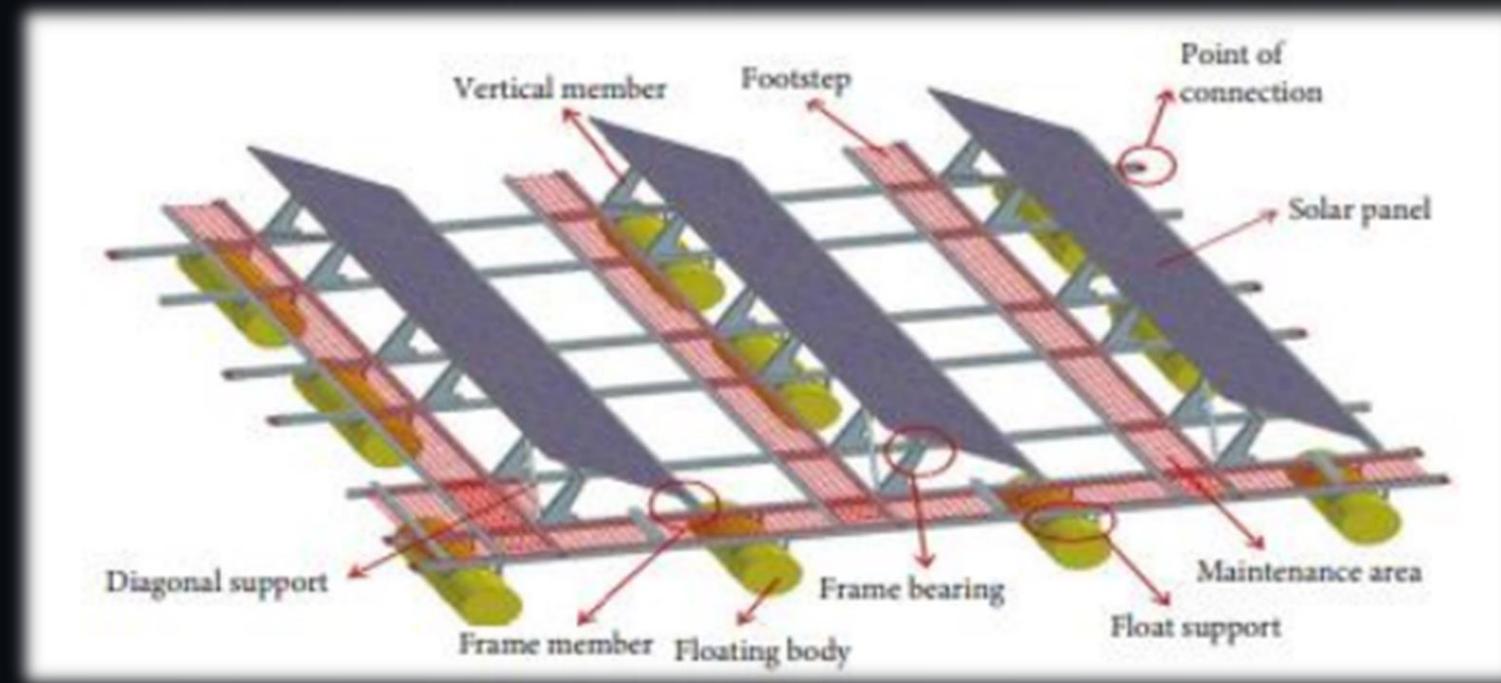


Figure 10. Frame Array Design



Figure 11. Independent Floating Modular Design

Source:

M. Elshafei et al., "Study of Massive Floating Solar Panels over Lake Nasser," Journal of Energy, vol. 2021, Article ID 6674091, 17 pages, 2021. [Online]. Available: <https://doi.org/10.1155/2021/6674091>

Electrical Layout

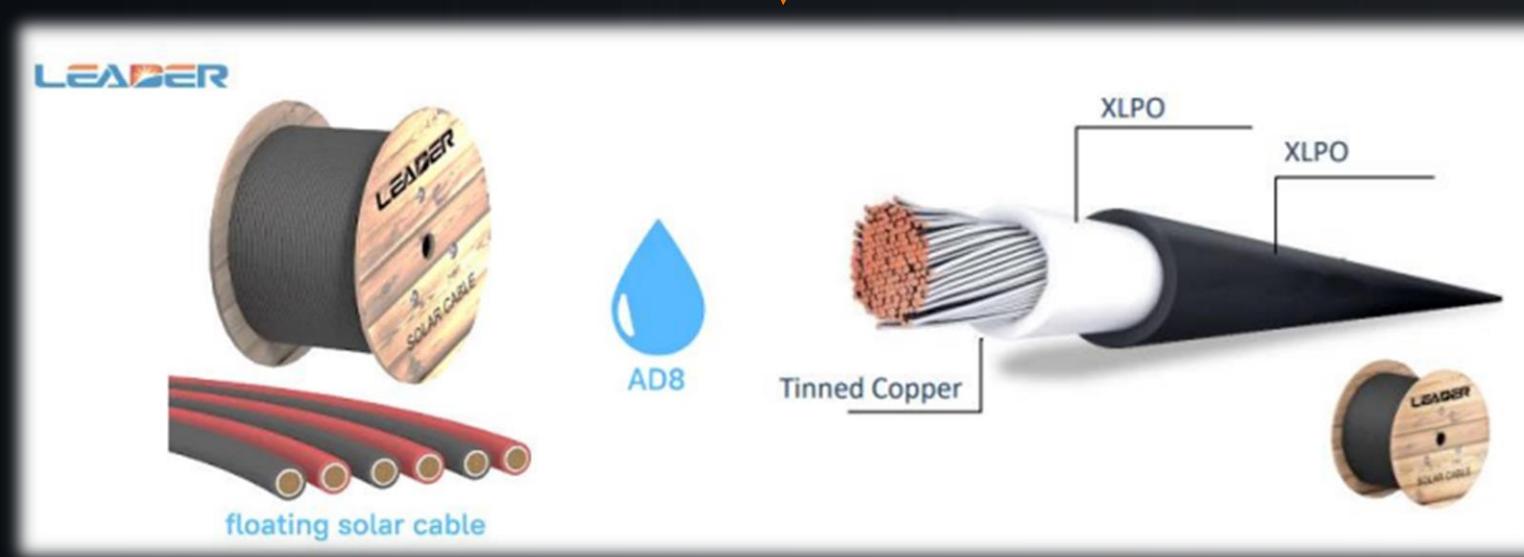


Figure 12. MC4 WiLEADER® Floating Solar Cable



Figure 13. Fronius's String Inverters

Source:

"JA Solar supplies modules for first floating PV plants," Energy Digital. [Online]. Available: <https://energydigital.com/renewable-energy/ja-solarsupplies-modules-first-floating-pv-plants>

Source:

"Why string inverters for PV systems," Fronius. [Online]. Available: <https://www.fronius.com/en-us/usa/solar-energy/home-owners/blog/why-stringinverters-for-pv-system>

FPV Power Plants Review

- 1) Small Size Power Plants
(up to 500 kWp)**

- 2) Medium Size Power Plants
(500 to 1500 kWp)**

- 3) Large Size Power Plants
(above 1500 kWp)**

Source:

S. S. Patil (Desai), M. M. Wagh, and N. N. Shinde, "A Review on Floating Solar Photovoltaic Power Plants," in International Journal of Scientific and Engineering Research, June 2017.

FPV Power Plants Review



Figure 14. California, USA, 175 kWp

Source:

"Floatovoltaics: Far Niente Wynery's floating solar power,"

Inhabitat. [Online].

Available: <https://shorturl.at/mwAR5>



Figure 15. Inami Town, Japan, 1428 kWp

Source:

Ciel et Terre, "Floating solar system," [Online].

Available: <http://www.ciel-et->



Figure 16. Walton-on-Thames, UK, 6338 kWp

Source:

Ciel et Terre, "QE-2 Project," [Online].

Available: <https://ciel-et-terre.net/project/qe-2/>

| 03 |

Project Design



Perimeter
15,772.53 m

Area
3,609,849.04 m²

Site Analysis

Figure 17-a. Site Data By Google Earth
(Al-Aqoul Lake)

Site Analysis

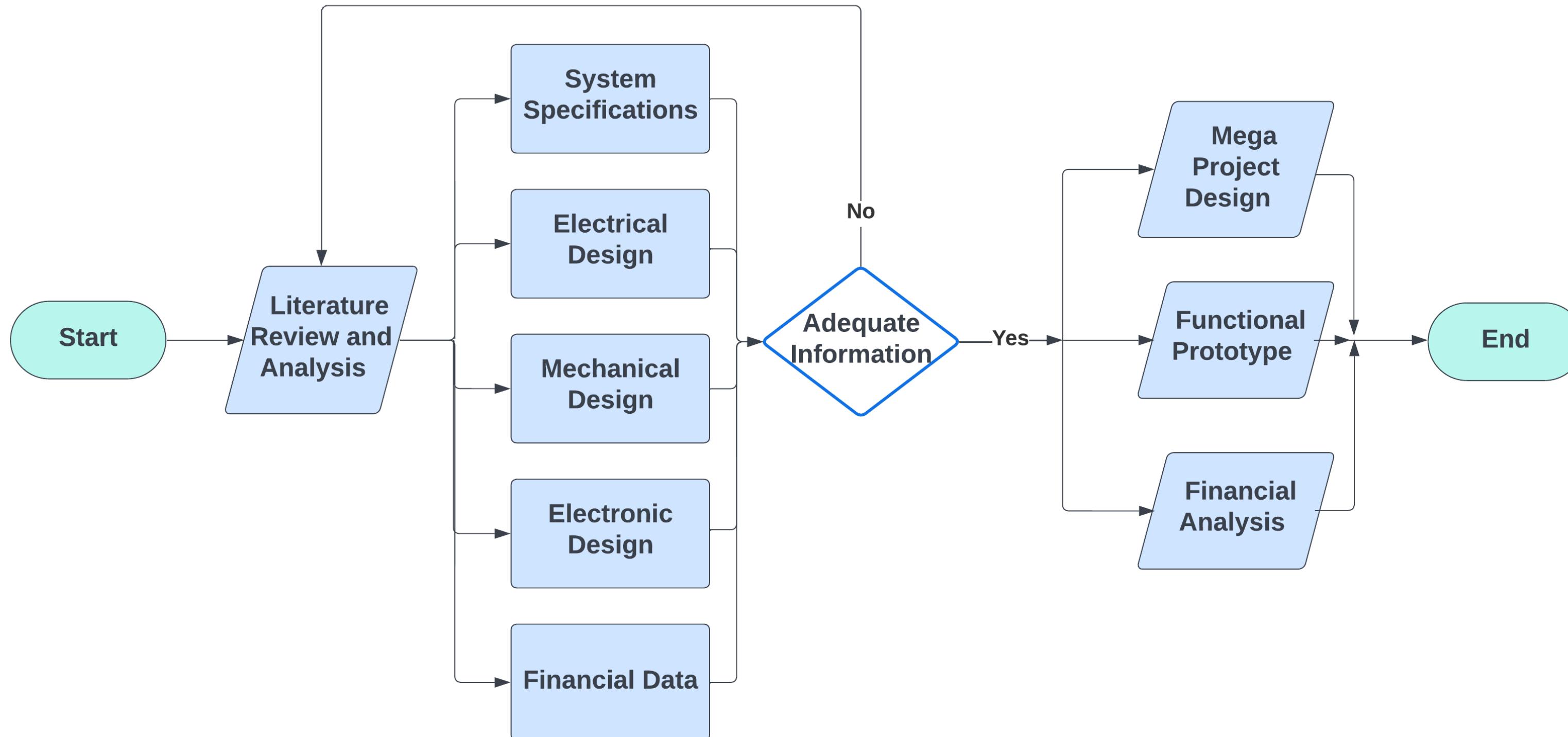


Figure 17-b. Site Photo, by us ☺
(Al-Aqoul Lake)

Site Analysis



Figure 17-c. Another Site Photo, by us ☺
(Al-Aqoul Lake)



Project Flow Chart

Mechanical Designs

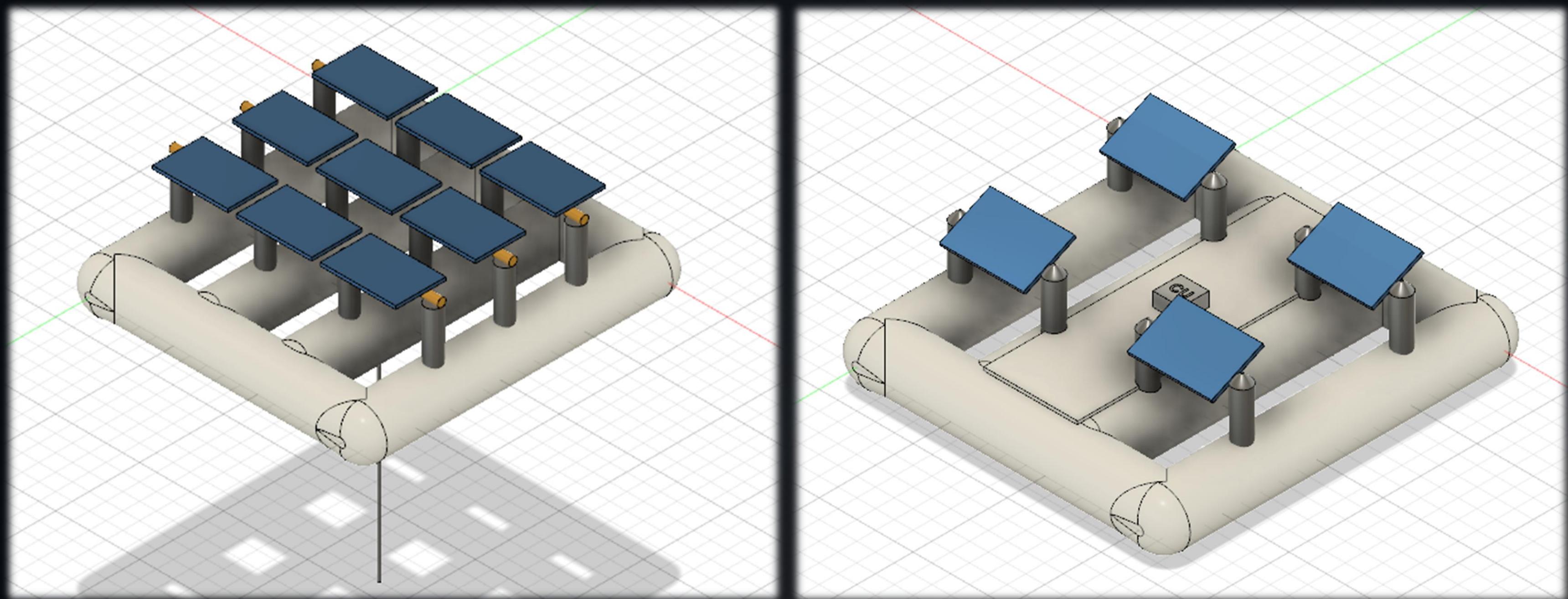


Figure 18. Mechanical Structures
(Fusion-360 Program)

Depth Warning System

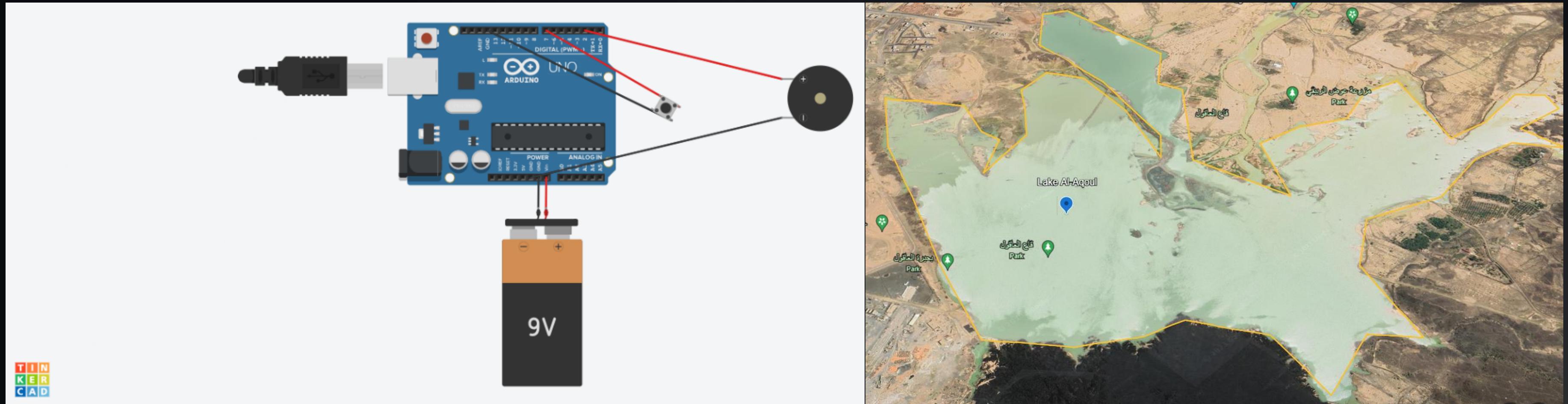
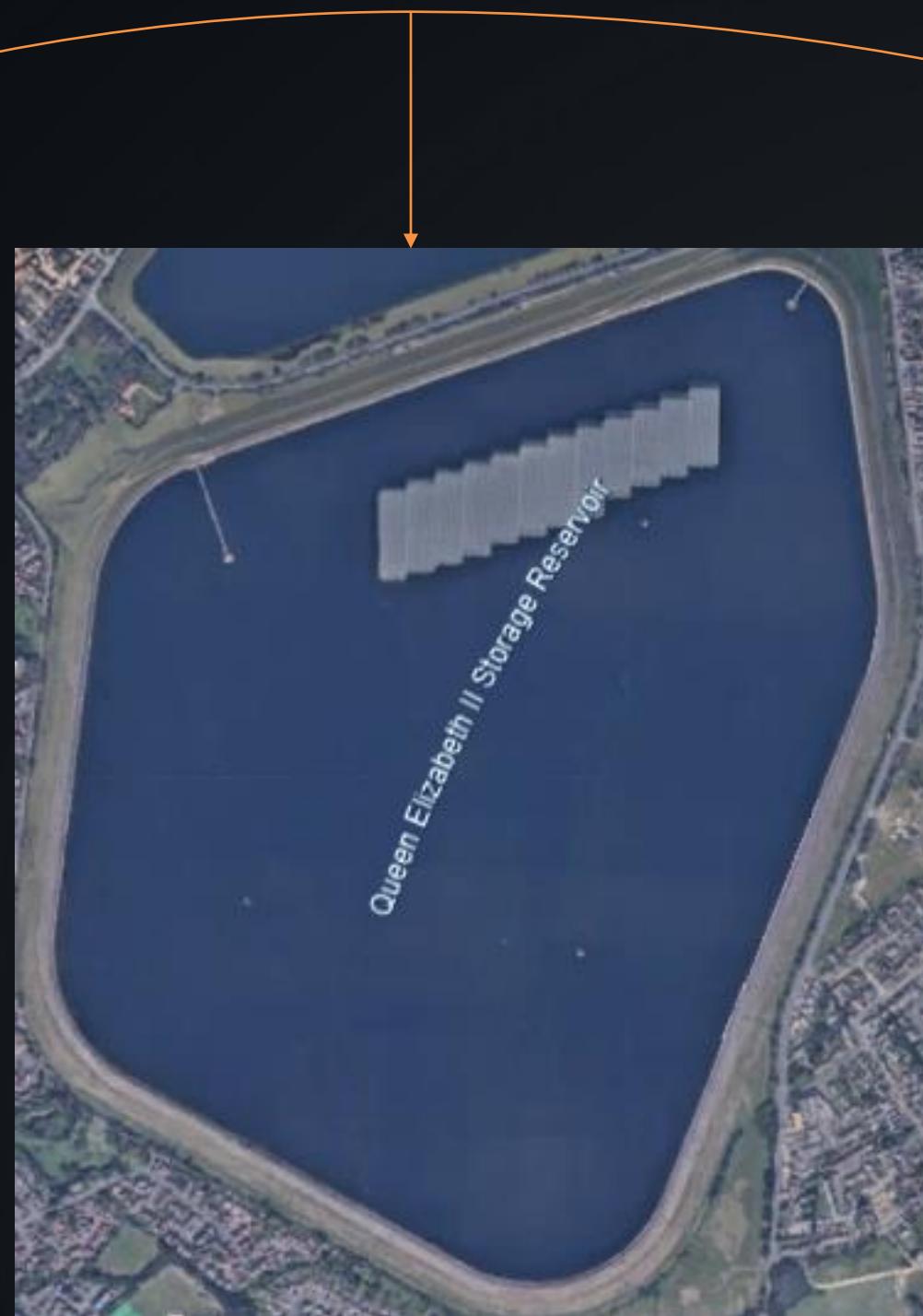


Figure 19. Electronic Design
(TINKERCAD Program)

Electrical Design Reasoning



Sembcorp FPV Farm



FPV of Queen Elizabeth II reservoir



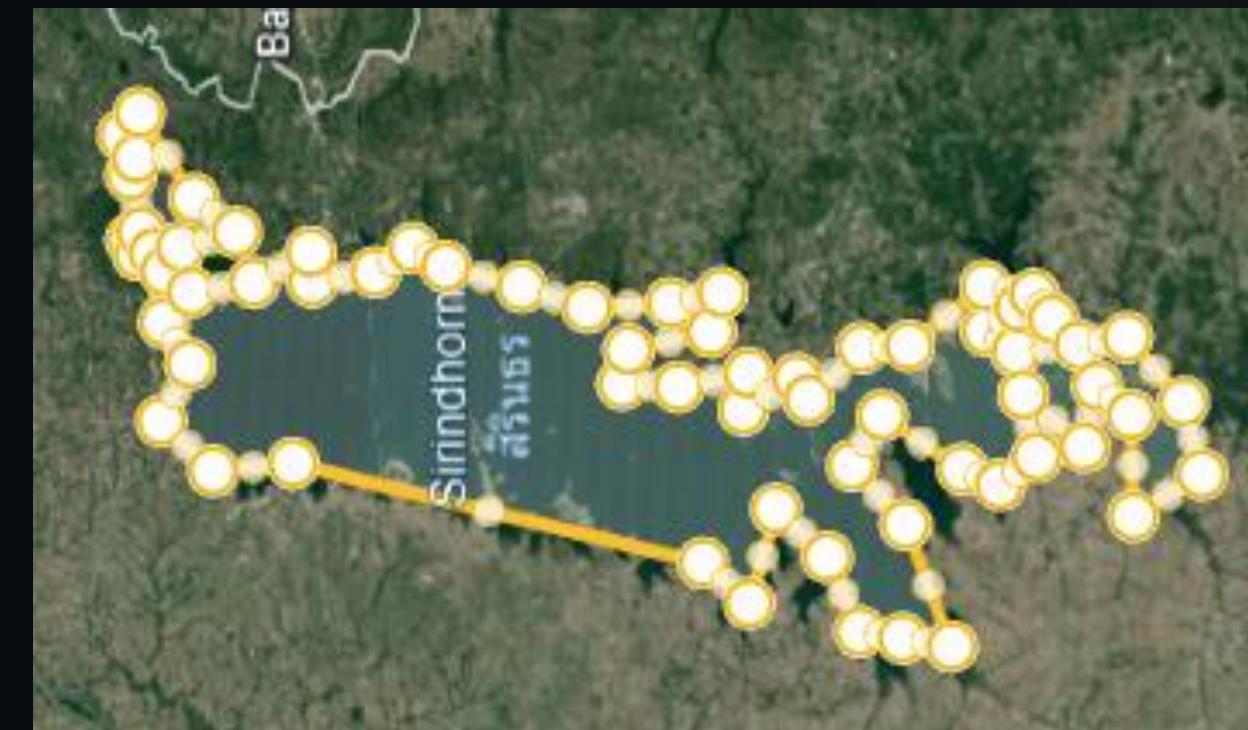
Sirindhorn Dam Floating Solar Farm

FPV of Queen Elizabeth II reservoir



- Location: The UK's largest floating solar farm is situated on the Queen Elizabeth II reservoir near Walton-on-Thames, Surrey.
- Number of Panels: It comprises more than 23,000 solar photovoltaic panels.
- Capacity: The total capacity of this floating solar farm is 6.3 megawatts (MW).
- Panels area = **57,500 m²**
- lake area = **1 279 000 m²**
- % of solar system = **4.50%**

Sirindhorn Dam Floating Solar Farm



- Location: Sirindhorn, Thailand.
- Number of Panels: 145,000 solar photovoltaic panels.
- Capacity: The total capacity of this floating solar farm is 45 megawatts (MW).
- Panels area = $121,000 \text{ m}^2$
- lake area = $2\,000\,000 \text{ m}^2$ (area taken manually, not available on internet)
- % of solar system = less than 1%

Sembcorp FPV Farm



- Location: Singapore.
- Number of Panels: 122,000 solar photovoltaic panels.
- Capacity: The total capacity of this floating solar farm is 60 megawatts (MW).
- Panels area = $450,000 \text{ m}^2$
- lake area = $1\ 235\ 737 \text{ m}^2$ (area taken manually, not available on internet)
- % of solar system = 36.42%

Electrical Design Formulation

Due to:

1. Available water area

2. System design

3. Lake topography

The System Size:

- **10% of the lake's Area**
- **The system's area = 360,985 square meters**
- **137,600 Panels of 545W each**

Electrical Design

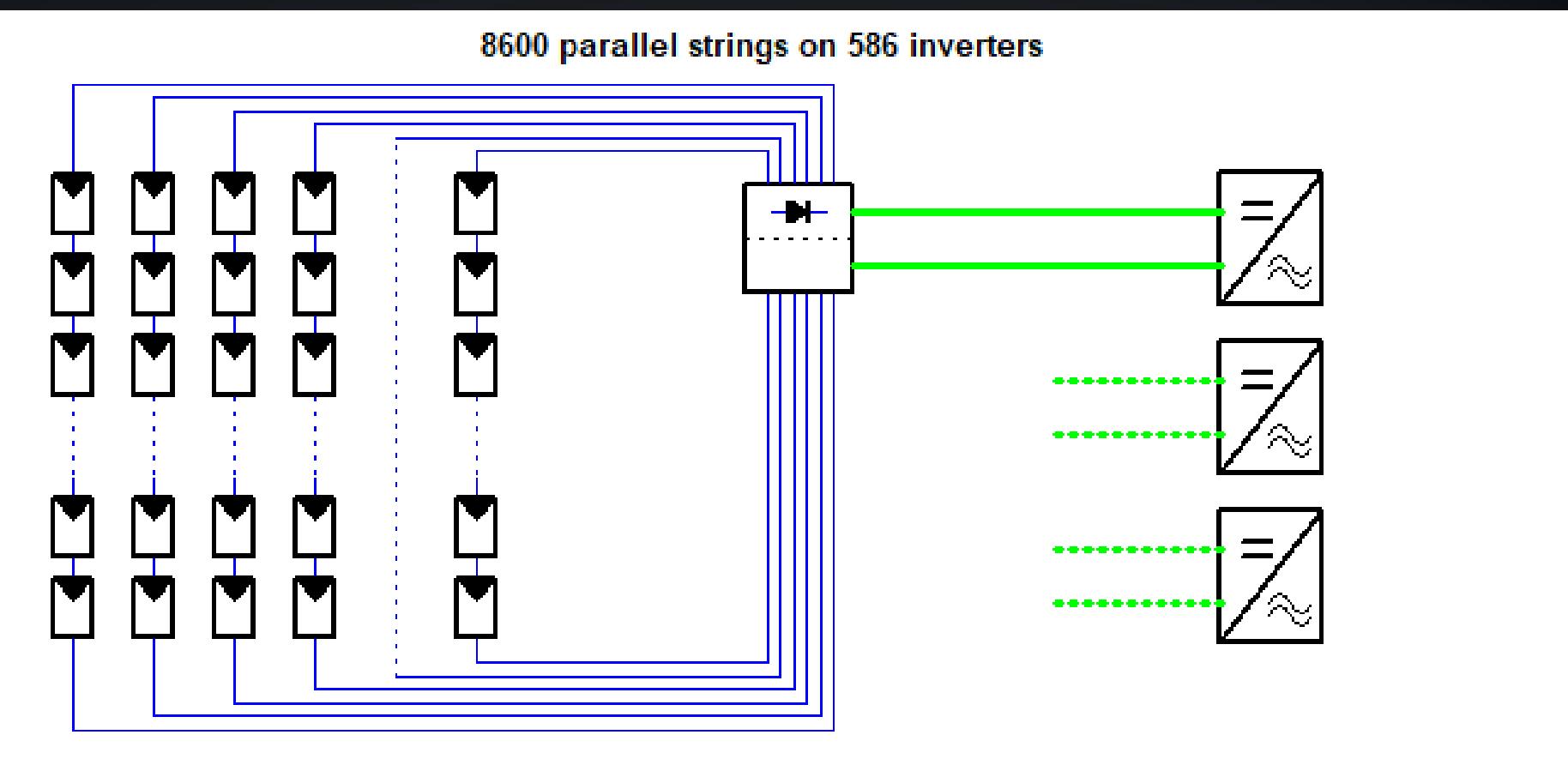
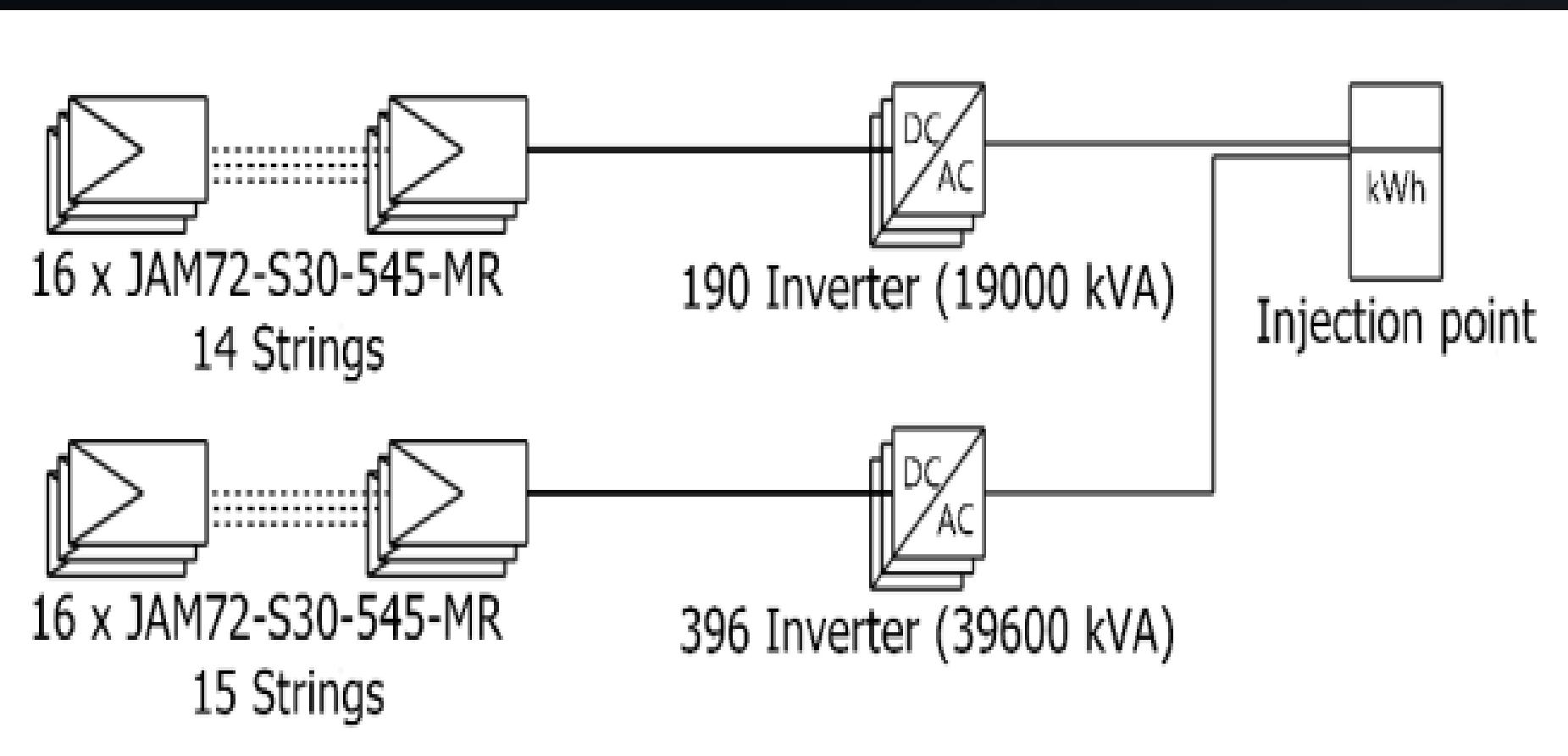


Figure 20. Electrical Design
(PVsyst Program)

Electrical Design Parameters

Albedo Design conditions Other limitations Preferences

Site-dependent design parameters

Reference temperatures for array design with respect to the inverter input voltages

Lower temperature for Absolute Voltage limit: -10 °C (Default)

Winter operating temperature for $V_{mpp\text{Max}}$ design: 20 °C

Usual operating temperature under 1000 W/m²: 50 °C

Summer operating temperature for $V_{mpp\text{Min}}$ design: 60 °C

Other design parameters

Array Max. voltage: IEC (usually 1000 V) UL (usually 600 V)

μV_{oc} value: From one-diode model From specification

Limit overload loss for design: 3.0 %

Transposition Model for this project: Hay model (robust) Perez-Ineichen model (sophisticated)

AC losses power reference: $P_{Nom\text{PV(ac)}} \text{ at STC}$ $P_{Nom} \text{ (inverters)}$

Circumsolar treatment: Included in diffuse Separate treatment

Basic model parameters

Shunt resistance: R_{sh} 240 Ohm Default

Series resistance (model): R_s 0.193 Ohm

Max. series res. for the model: 0.201 Ω

Series res. (apparent): dV/dI 0.33 Ω

Diode satur. current: I_{oRef} 0.025 nA

Diode quality factor: Gamma 0.99 - 0.000/K

Voltage temp. coeff.: μV_{oc} -135.0 mV/°C

The I/V characteristics has to pass through the three given points I_{sc} , M_{pp} and V_{oc} . Diode saturation current, quality factor and Voltage temperature coefficient are determined by this requirement.

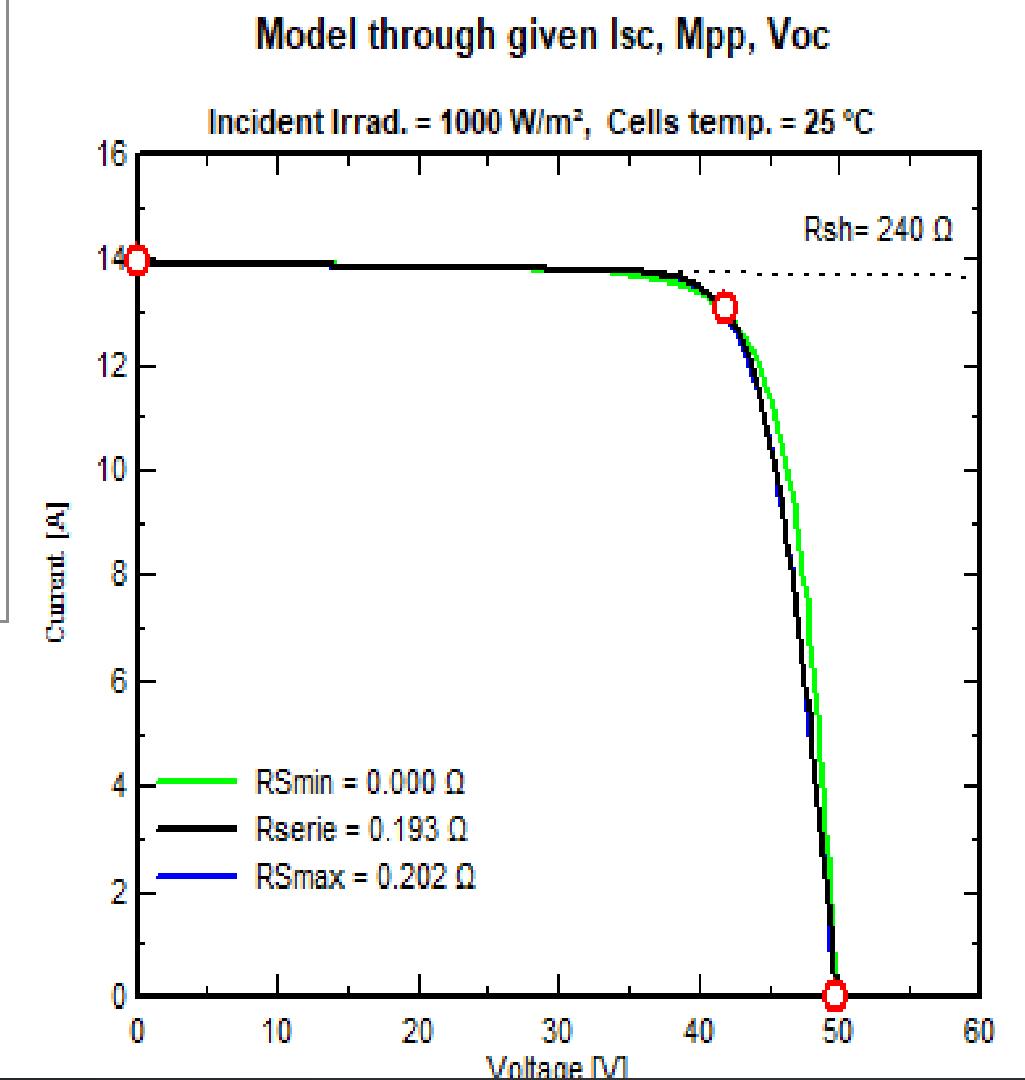


Figure 21. Main Parameters.

Figure 22. PV Panel Parameters.

Electrical Design Parameters

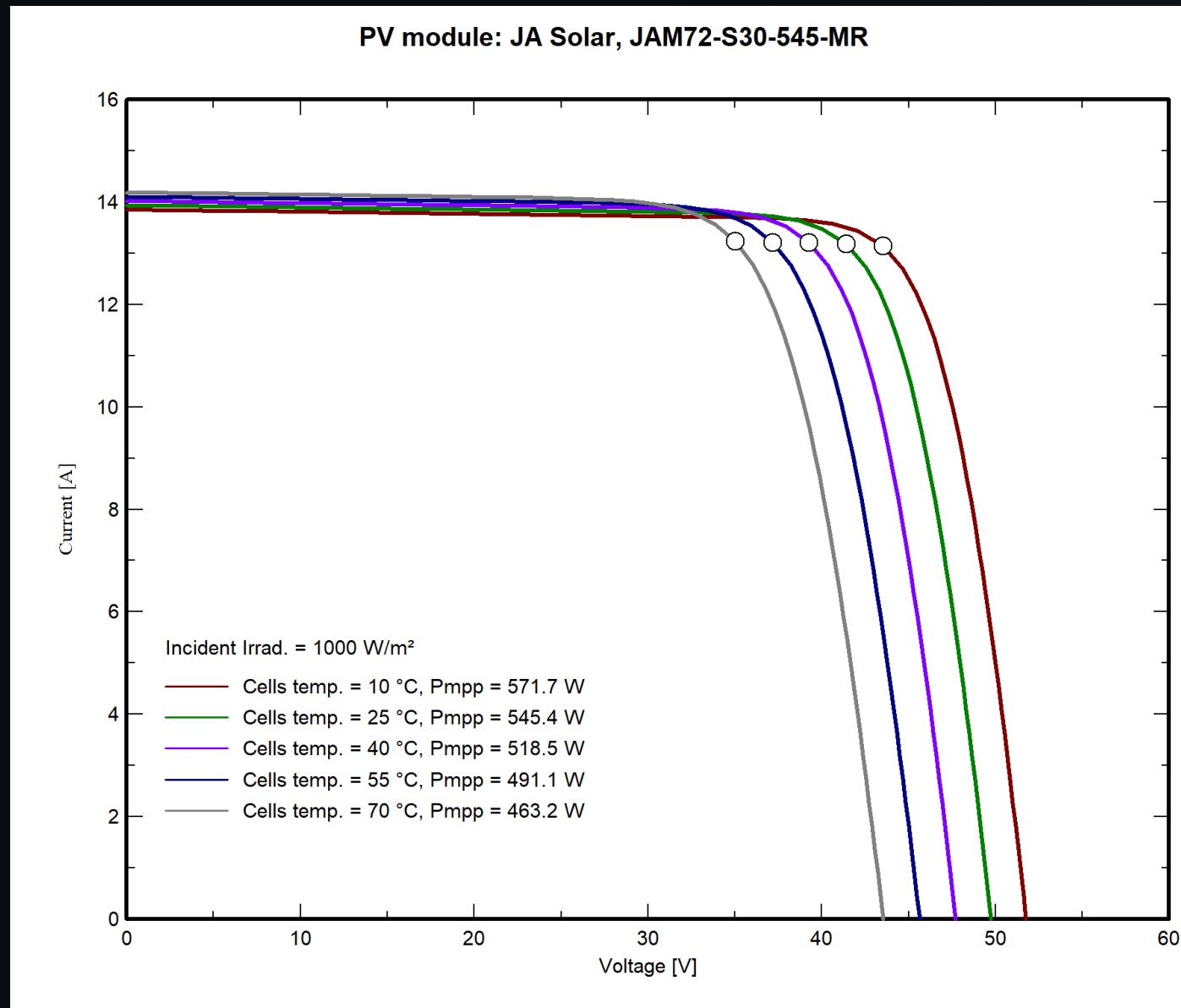


Figure 23. PV Panel V-I Curve with
Varying Temperature

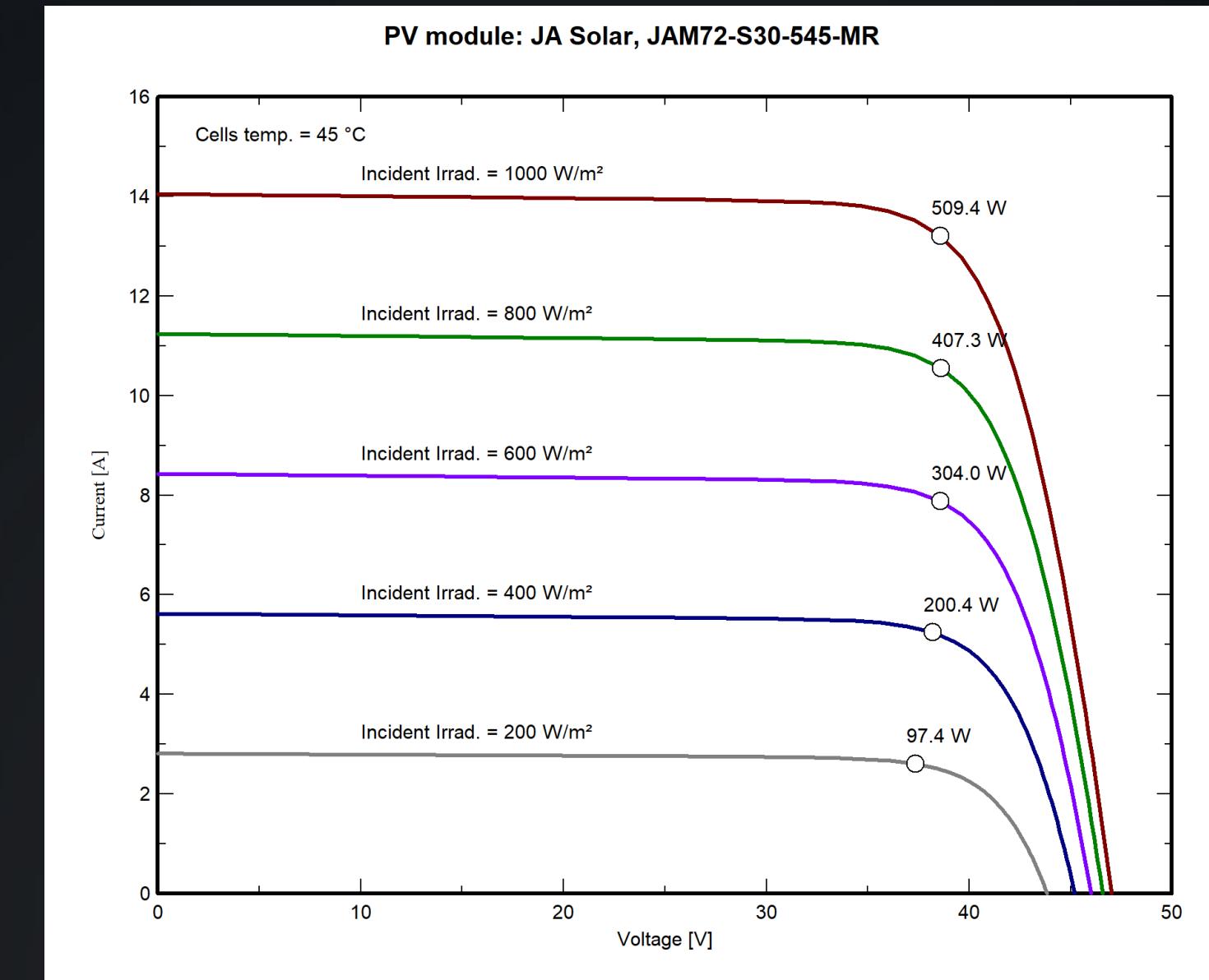


Figure 24. PV Panel V-I Curve with
Varying Irradiance

Electrical Design Parameters

Sub-array

Sub-array name and Orientation

Name: PV Array	Tilt: 26°
Orient.: Fixed Tilted Plane	Azimuth: 0°

Pre-sizing Help

No sizing Enter planned power: 76158.0 kWp
 Resize ... or available area(modules): 360985 m²

Select the PV module

Available Now Filter: All PV modules Maximum nb. of modules: 139740

JA Solar 545 Wp 35V Si-mono JAM72-S30-545-MR Since 2021 Manufacturer-RETC

Use optimizer

Sizing voltages : Vmpp (60°C) 36.5 V
 Voc (25°C) 49.7 V

Select the inverter

Available Now Output voltage 400 V Tri 50Hz 50 Hz
 60 Hz

Fronius International 100 kW 580 - 930 V TL 50/60 Hz Tauro Eco 99-3-P Since 2020

Nb. of inverters: 586 Operating voltage: 580-930 V Global Inverter's power: 58600 kWac
 Input maximum voltage: 1000 V

Design the array

Number of modules and strings

Mod. in series: 16 <input type="button" value="Sizing"/>	<input checked="" type="checkbox"/> between 16 and 20
Nb. strings: 8600	<input type="checkbox"/> between 6720 and 8685
Overload loss: 2.7 %	<input type="checkbox"/>
Pnom ratio: 1.28	<input type="checkbox"/>
Nb. modules: 137600	Area: 355455 m ²

Operating conditions

Vmpp (60°C) 584 V
 Vmpp (20°C) 674 V
 Voc (25°C) 796 V

The inverter power is slightly undersized.

Plane irradiance: 1000 W/m² Max. in data STC
 Impp (STC) 112144 A Max. operating power (at 1100 W/m² and 50°C) 75644 kW
 Isc (STC) 119798 A
 Isc (at STC) 119798 A Array nom. Power (STC) 74992 kWp

Figure 25. System Parameters.

Electrical Design Parameters

Thermal parameter Ohmic Losses Module quality - LID - Mismatch Soiling Loss IAM Losses Auxiliaries Aging Unavailability Spectral correction

Field Thermal Loss Factor

Thermal Loss factor $U = U_c + U_v * \text{Wind vel}$?

Constant loss factor U_c 29.0 W/m²K

Wind loss factor U_v 0.0 W/m²K m/s

Default value acc. to mounting

"Free" mounted modules with air circulation
 Domes
 Semi-integrated with air duct behind
 Integration with fully insulated back

The losses parameters changes:

1. Thermal losses decrement.
2. Default values for: Ohmic losses, Model quality, Model Mismatch losses, String
- Voltage mismatch, IAM losses, Unavailability of the system, and Spectral correction.
3. Soiling losses are set to 2% instead of 3%.
4. No auxiliaries' settings.

Figure 26. Losses settings

| 04 |

Experimentation & Implementation

Software Selection

PVsyst



Fusion-360



TinkerCAD



Hardware Selection

- Components -

Polycrystalline Solar Panel



SOLAR PANEL	
Test condition: 1000W/m Am1.5 Module at 25°C	
Rated voltage(Vm)	6V
Rated current (Im)	1.6A
Short-circuit current (Isc)	1.99A
Open-circuit voltage(Voc)	7.2V
Peak power (Pm)	10W
Dimension (mm)	350*190*17



PVC Pipes



PVC Elbows and Connectors



Hardware Selection

- Instruments -

Hacksaw



Digital Multimeter



Measuring Tape



CPVC Adhesive



Prototype Building Process

Stage 1: Frame Construction



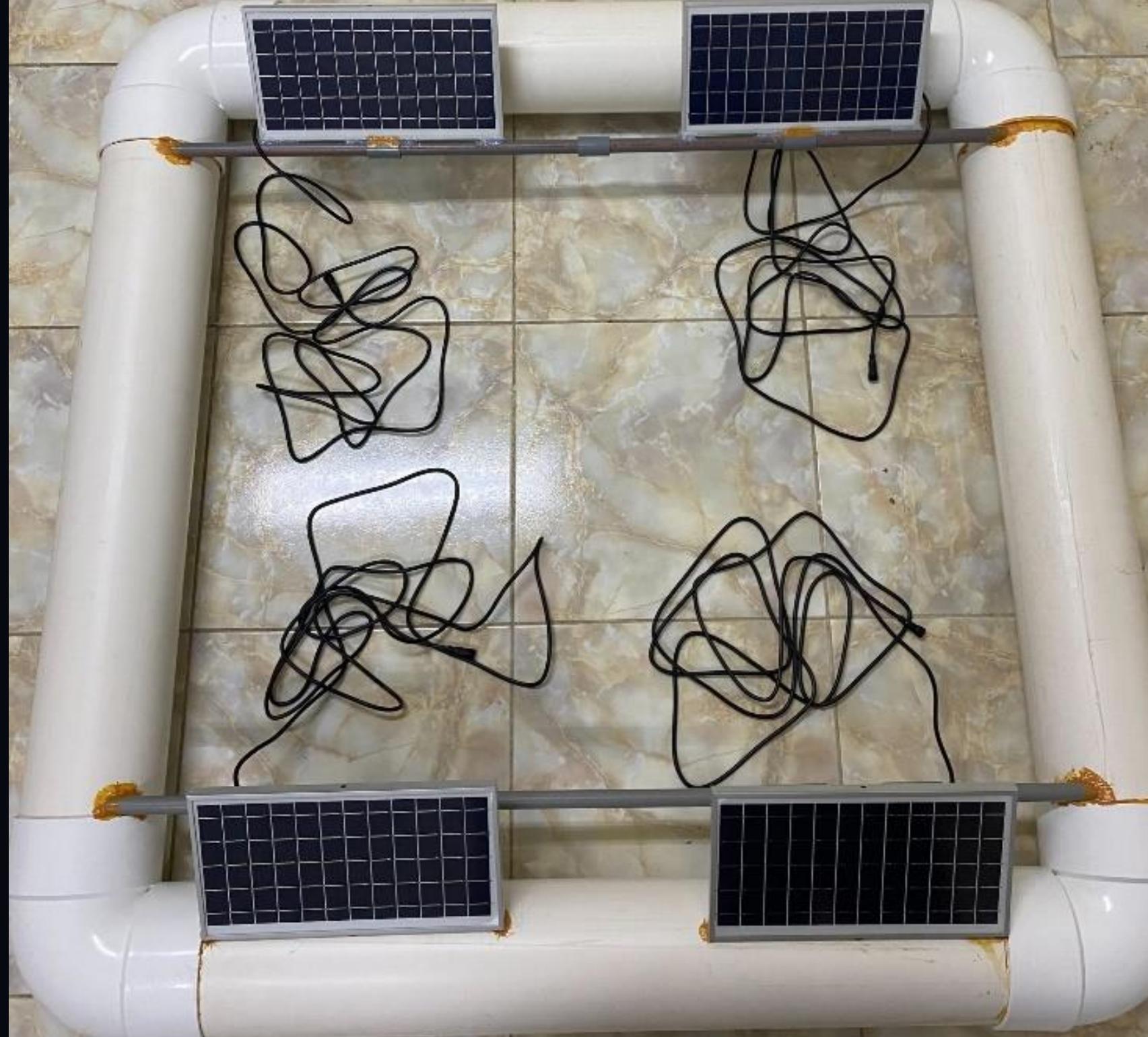
- ✓ Cutting and Measuring
- ✓ Assembly
- ✓ Sealing and Waterproofing

Stage 2: Structural Reinforcement for Solar Panel Installation



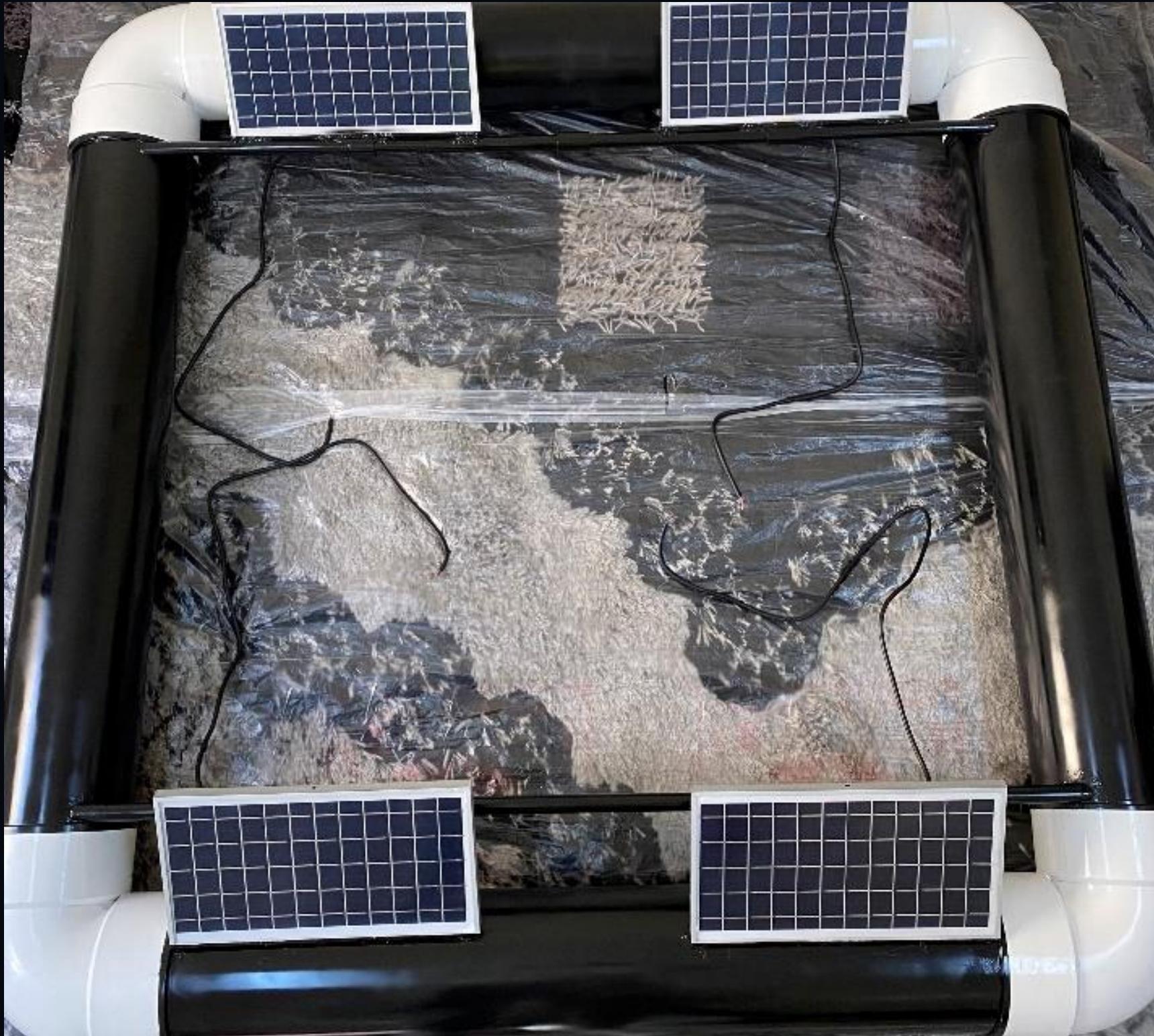
- ✓ Installation of Support Rods
- ✓ Securing the Rods
- ✓ Load Testing

Stage 3: Solar Panel Installation



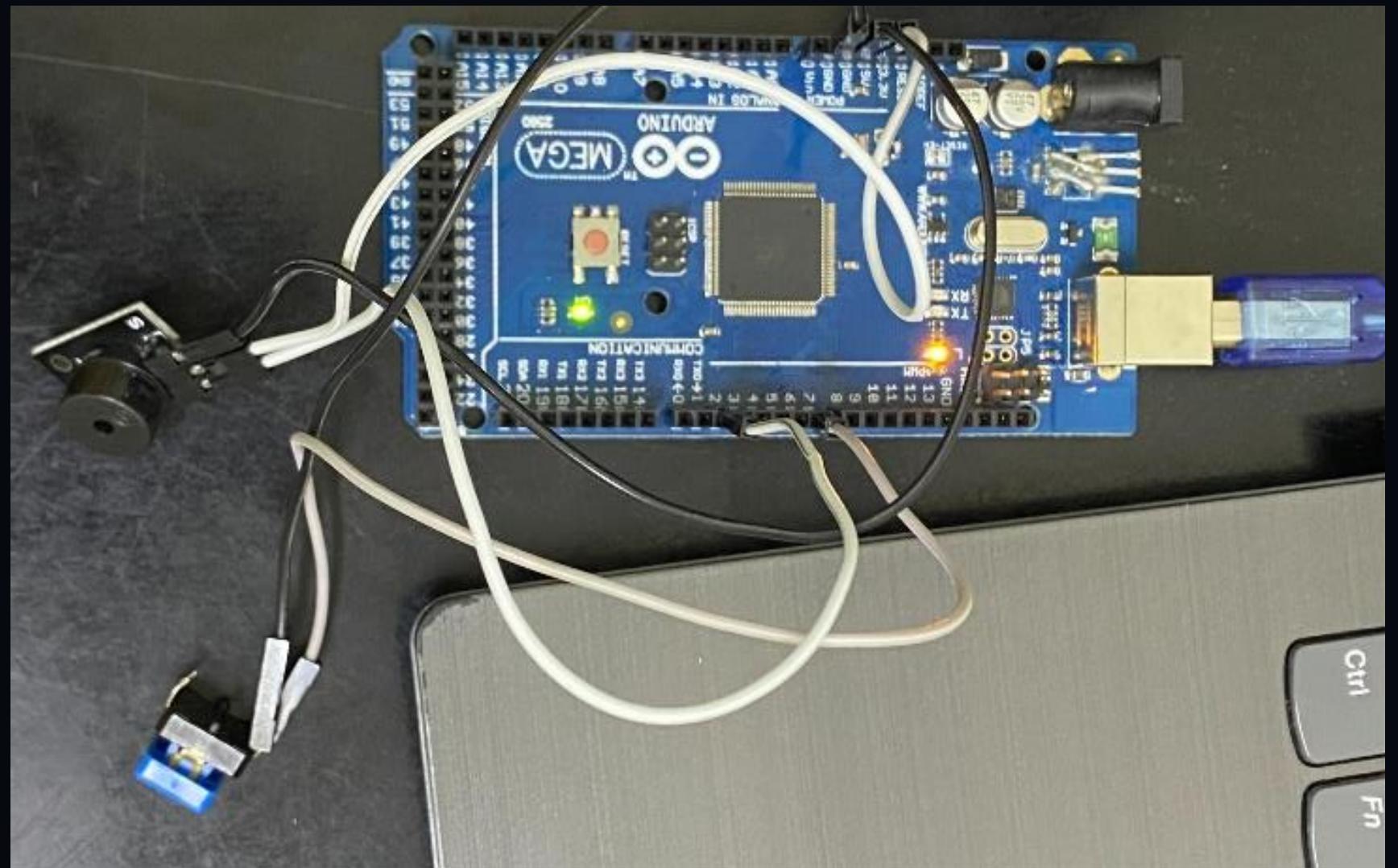
- ✓ Mounting the Solar Panels
- ✓ Ensuring Durability

Stage 4: Aesthetic Enhancement and Wiring Preparation



- ✓ Color Change of PVC Frame
- ✓ Preparing for Final Connections

Additional Setups



Arduino Setup

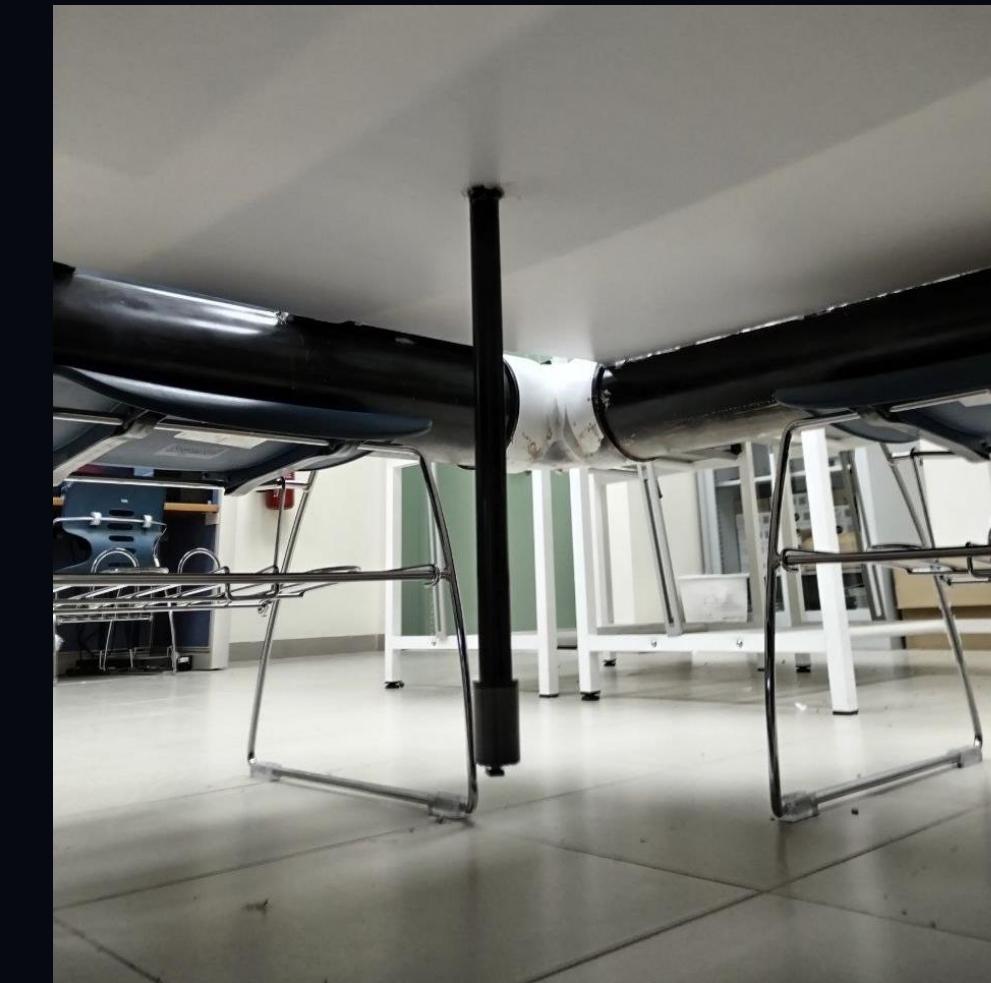


Water Level Sensor

Final Stage: Installation of Control Unit and Final Assembly



- ✓ Installation of the Cork Base
- ✓ Building the Control Unit



Lake Depth Measurement



Step-1



Step-2



Step-3

Budget

No.	Item	Quantity	Cost (SAR)	Total Cost (SAR)
1	Waterproof Glue	1	25	25
2	Plastic Rods (for the bottom)	4	-	56.67
3	Plastic Joints	4	-	92
4	Plastic Rods (for holding panels)	4	-	22.02
5	PV Solar Panels (10W each)	4	40 each	160
6	Control Unit Plastic Box	1	5	5
7	Cork Plate (70*150)	2	10 each	20
8	A3 Cover Paper	1	10	10
9	Reflecting Tape	1	5	5
10	Black Color Spray	7	-	68
11	Arduino Uno	1	45	45
12	Buzzer	1	5	5
13	Push Button	1	5	5
14	9V Battery	1	4	4
	Total Cost			522.69

Timeline

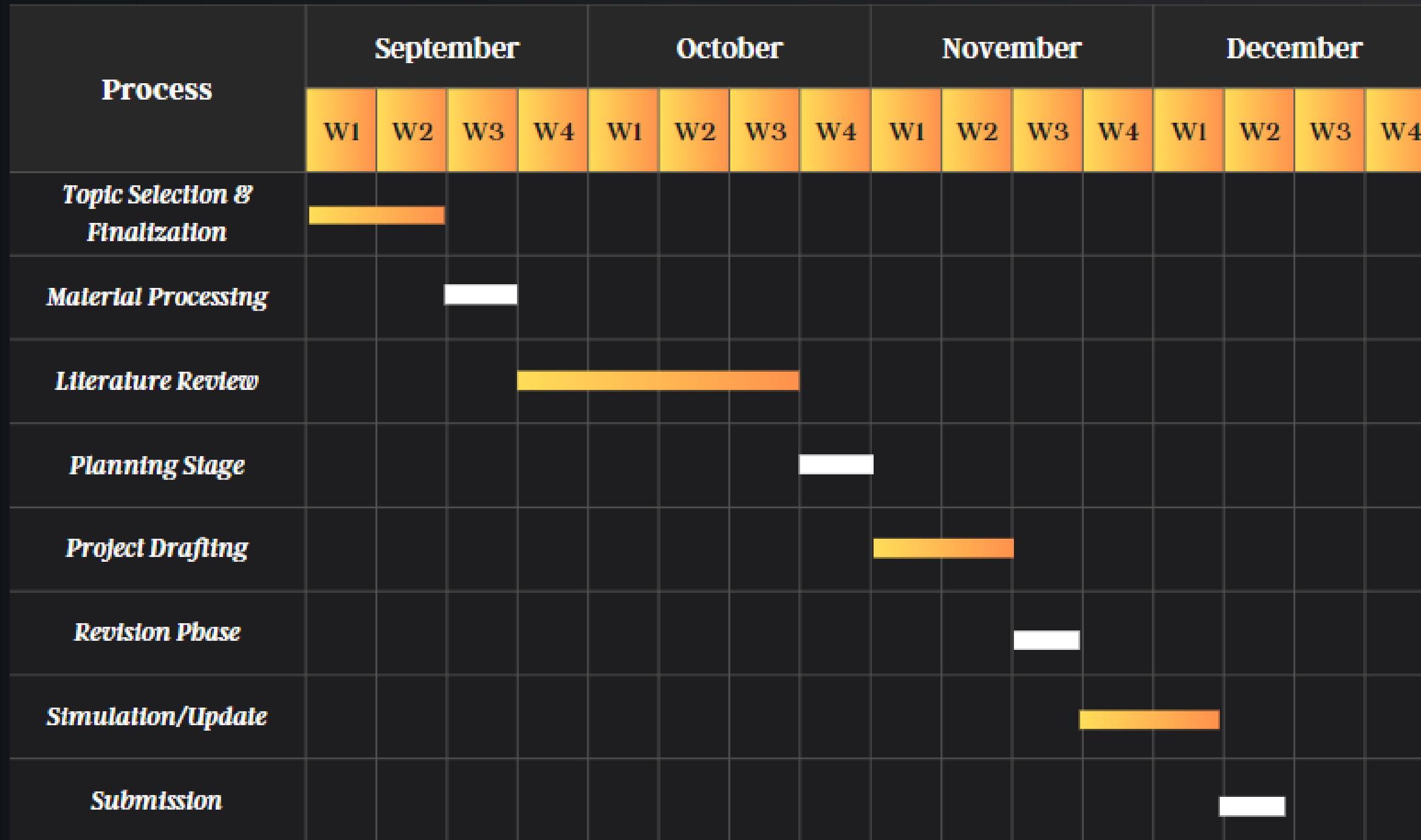


Figure 27. Gantt Chart of Capstone I

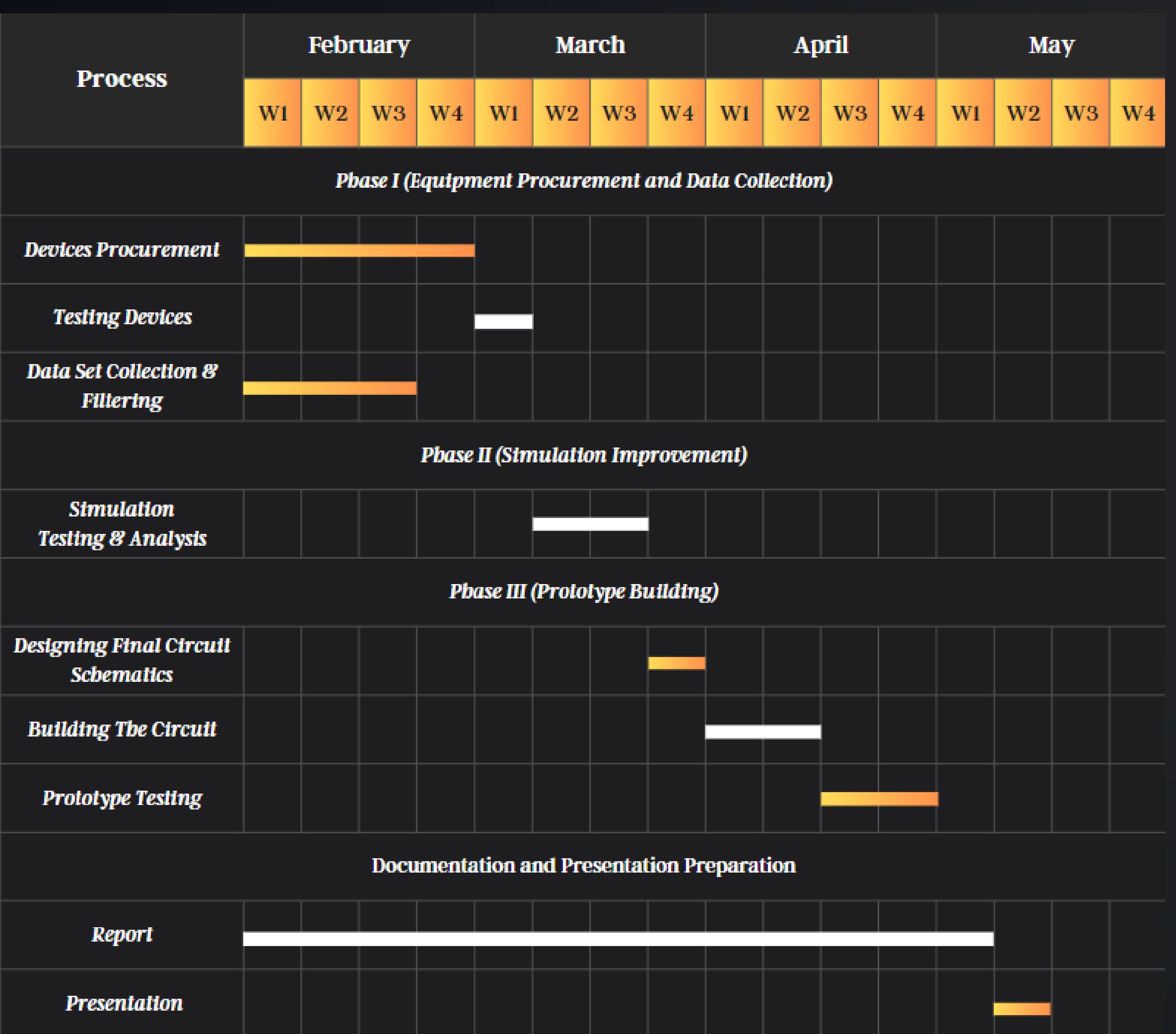


Figure 28. Gantt Chart of Capstone II

| 05 |

Results & Discussion

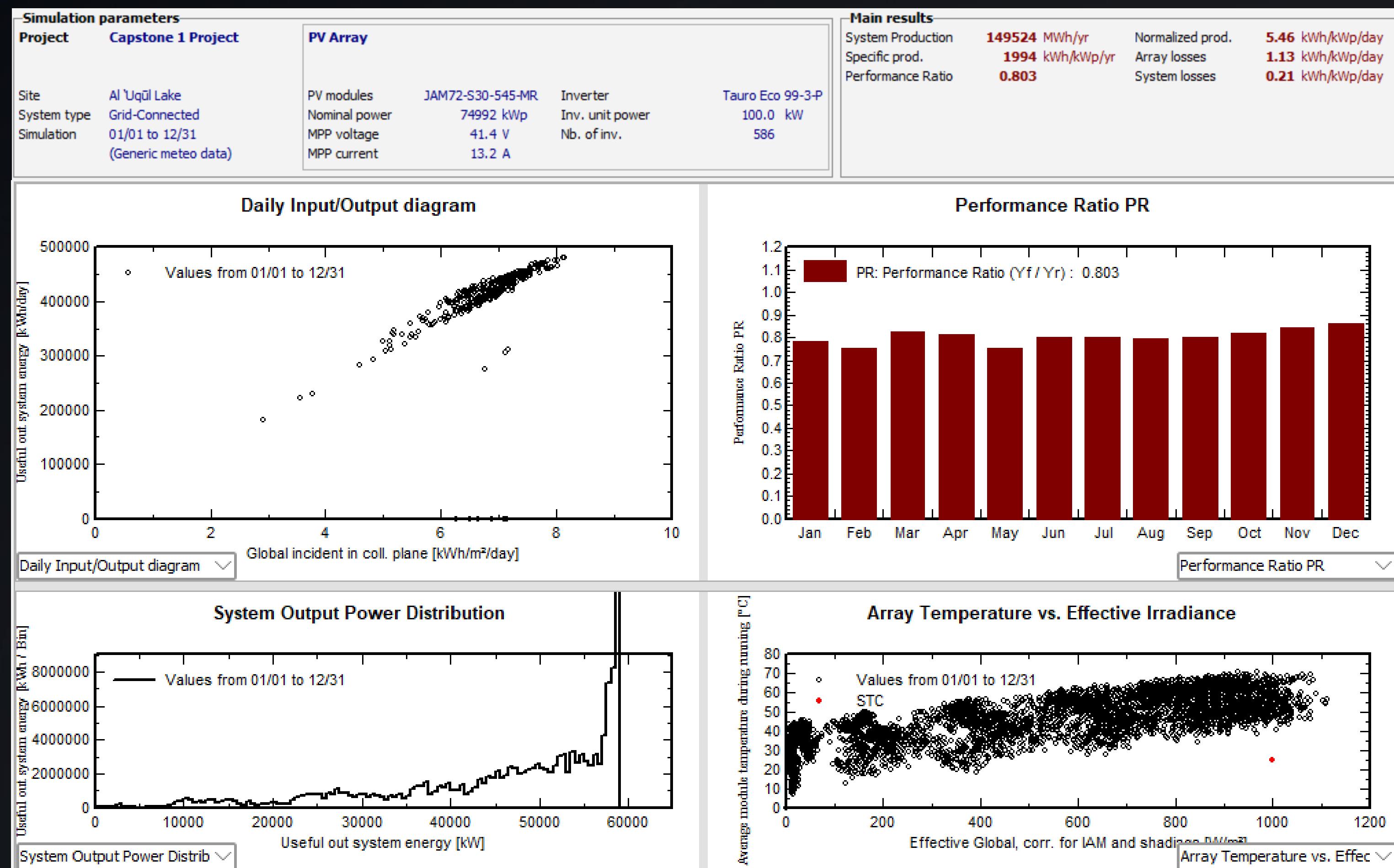


Figure 29. PVsyst Results

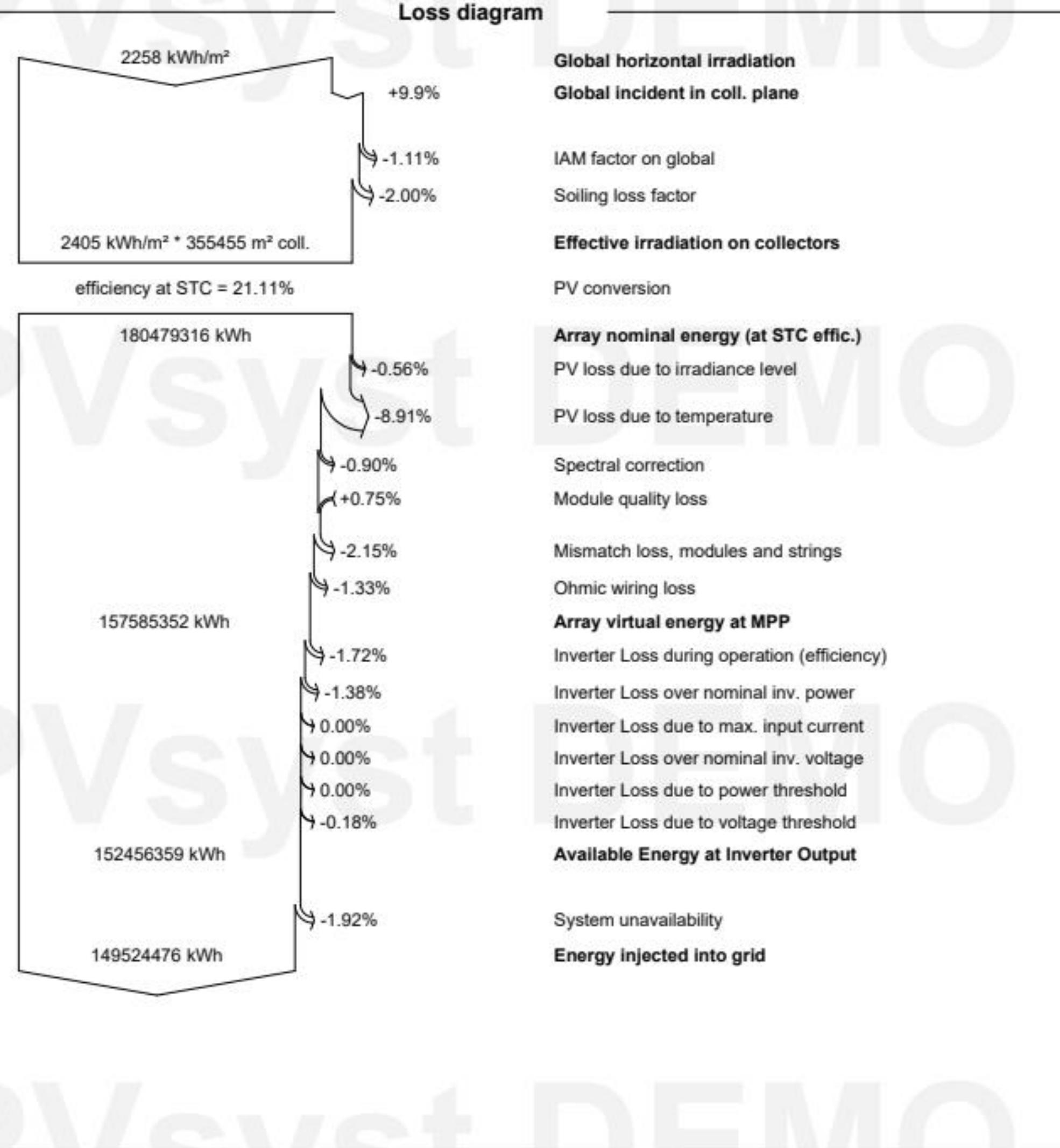


Figure 30. Results of Loss Diagram

Financial Study



Initial Capital Investment



318,836,800 SAR

Annual Revenue



26,914,320 SAR

Break-even Point (kWh)



122,659,333 kWh

Prototype Presentation



Prototype Presentation



Discussion



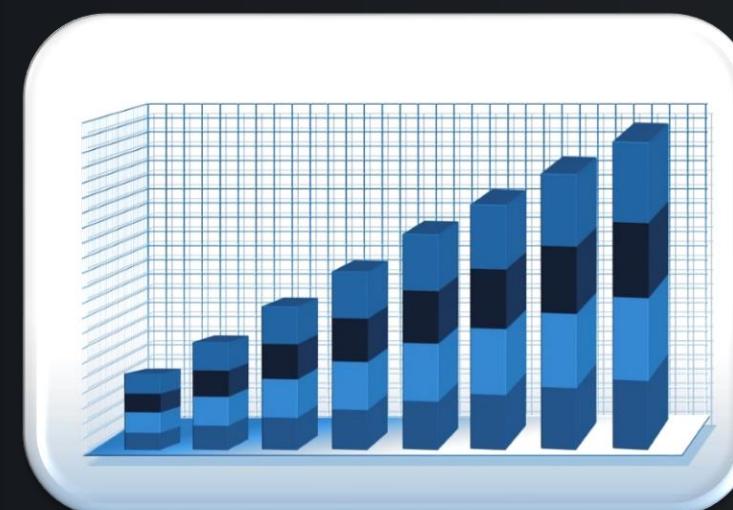
Skills and Knowledge
Required for the
Project



Learning Processes
and Techniques



Application of
Knowledge and Skills



Final Observations
and Statistics



Results evaluation

| 06 |

Conclusion

Summary

Project Importance:

- Sustainability and Environment
- Vision 2030
- Enhancing Efficiency

Project Outcomes:

- Functional Prototype
- Real Mega Project Design
- Financial Analysis

Important Results:

- ✓ 149,524 MWh/year
- ✓ Performance ratio of 0.803
- ✓ Break-Even pt. 122,659,333 kWh/yr

Future Recommendations



Integration of AI-Driven Technologies



Scalability and Expansion

Relevant EE Courses



EE-459 Renewable Energy



EE-404 Solar Cells & Photovoltaic
Systems

Work Division

Task	Person
Literature Review	Most Literature: Hamza
Mechanical Design	3D Design: Marwan
PVsyst Design and Analysis	Hamza and Marwan (Marwan Most)
Report Writing	Hamza and Marwan (equal tasks)
Presentation Slides Preparation	Design: Hamza. Content: Marwan.
Financial Study	Hamza and Marwan (Hamza Most)
Prototype Building Components	Marwan
Work Instruments	Hamza

Table 2. Work Division

Acknowledgment



References

- [1]. "Saudi Vision 2030 - Environment & Nature," Vision 2030, [Online]. Available: <https://www.vision2030.gov.sa/en/progress/environment-nature/>.
2023
- [2]. A. Amer, H. Attar, S. As'ad, S. Alsaqoor, I. Colak, A. Alahmer, M. Alali, G. Borowski, M. Hmada, and A. Solyman, "Floating Photovoltaics: Assessing the Potential Advantages and Challenges of Harnessing Solar Energy on Water Bodies," Journal of Ecological Engineering, vol. 24, no. 10, pp. 324–339, Aug. 2023. [Online]. Available: <https://doi.org/10.12911/22998993/170917>
- [3]. M. Elshafei et al., "Study of Massive Floating Solar Panels over Lake Nasser," Journal of Energy, vol. 2021, Article ID 6674091, 17 pages, 2021. [Online]. Available: <https://doi.org/10.1155/2021/6674091>
- [4]. "JA Solar supplies modules for first floating PV plants," Energy Digital. [Online]. Available: <https://energydigital.com/renewable-energy/ja-solarsupplies-modules-first-floating-pv-plants>
- [5]. "Why string inverters for PV systems," Fronius. [Online]. Available: <https://www.fronius.com/en-us/usa/solar-energy/home-owners/blog/why-stringinverters-for-pv-system>
- [6]. S. S. Patil (Desai), M. M. Wagh, and N. N. Shinde, "A Review on Floating Solar Photovoltaic Power Plants," in International Journal of Scientific and Engineering Research, June 2017.
- [7]. "Floatovoltaics: Far Niente Wynery's floating solar power," Inhabitat. [Online]. Available: <https://shorturl.at/mwAR5>
- [8]. Ciel et Terre, "Floating solar system," [Online]. Available: http://www.ciel-et-terre.net/essential_grid_category/floating-solar-system/
- [9]. Ciel et Terre, "QE-2 Project," [Online]. Available: <https://ciel-et-terre.net/project/qe-2/>



THANK YOU

Any Questions?