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Agrivoltaics

STRATEGY & IMPLEMENTATION PLAN

INTEGRATING SOLAR POWER, AGRICULTURE& WATER

MIDELT, MOROCCO

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Project Summary

Who?

Benmore Energy Limited;
green energy company

Founded in Scotland est. 2010

Specialize in the end-to-end delivery of renewable energy systems ; solar (PVs)

What?

Integrating solar panels and farming within the framework of agrivoltaics (solar farming) and implementing a pilot project

Where?

Midelt,
Morocco

Why?

Potential to increase land efficiency with the dual-use approach ; clean energy + food

Strategic pathway to boost revenue, reduce costs, and position Benmore as a regional leader in sustainable innovation

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Recommendations: Snapshot

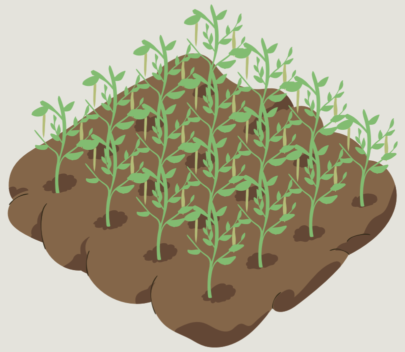
1 CROP SELECTION

Select one of the following crops or crop systems to plant under the solar panels:

Tomatoes, Peppers, and Garlic OR Carrots, Radishes and Onions: creates a system that compliment one another, fit well under PVs, do not compete for nutrients and share irrigation n needs

Apples: for the their high importance and potential

Cereals: such as barley or wheat (durum) for their drought and low-light tolerance



2 SUSTAINABLE IRRIGATION

Invest in the resources to utilize the energy from the solar panels to power an irrigation system (pump and drip).

Sustainable irrigation with APV system improves soil moisture, reducing irrigation needs especially when merged with AI.

Initial high costs can be outweighed by long-term ROI (alternative operational costs).

3 COMMUNITY ENGAGEMENT

Engaging with community members during the rudimentary phases of the project can increase support from the community.

The relationship can be cultivated through surveys and a communication platform to inform and educate them on project details and how this will positively impact their community.

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Stakeholders

Stakeholders	Role	Priority
3rd Party Industrial Company	Electricy Buyer	High
ONEE (The National Office of Electricy and Drinking Water)	Potential Electriciy Buyer	Medium
3rd Party Crop Buyer	Crop Buyer	High
Land Owner	Owns the land	High
Community	Support, Labor	High

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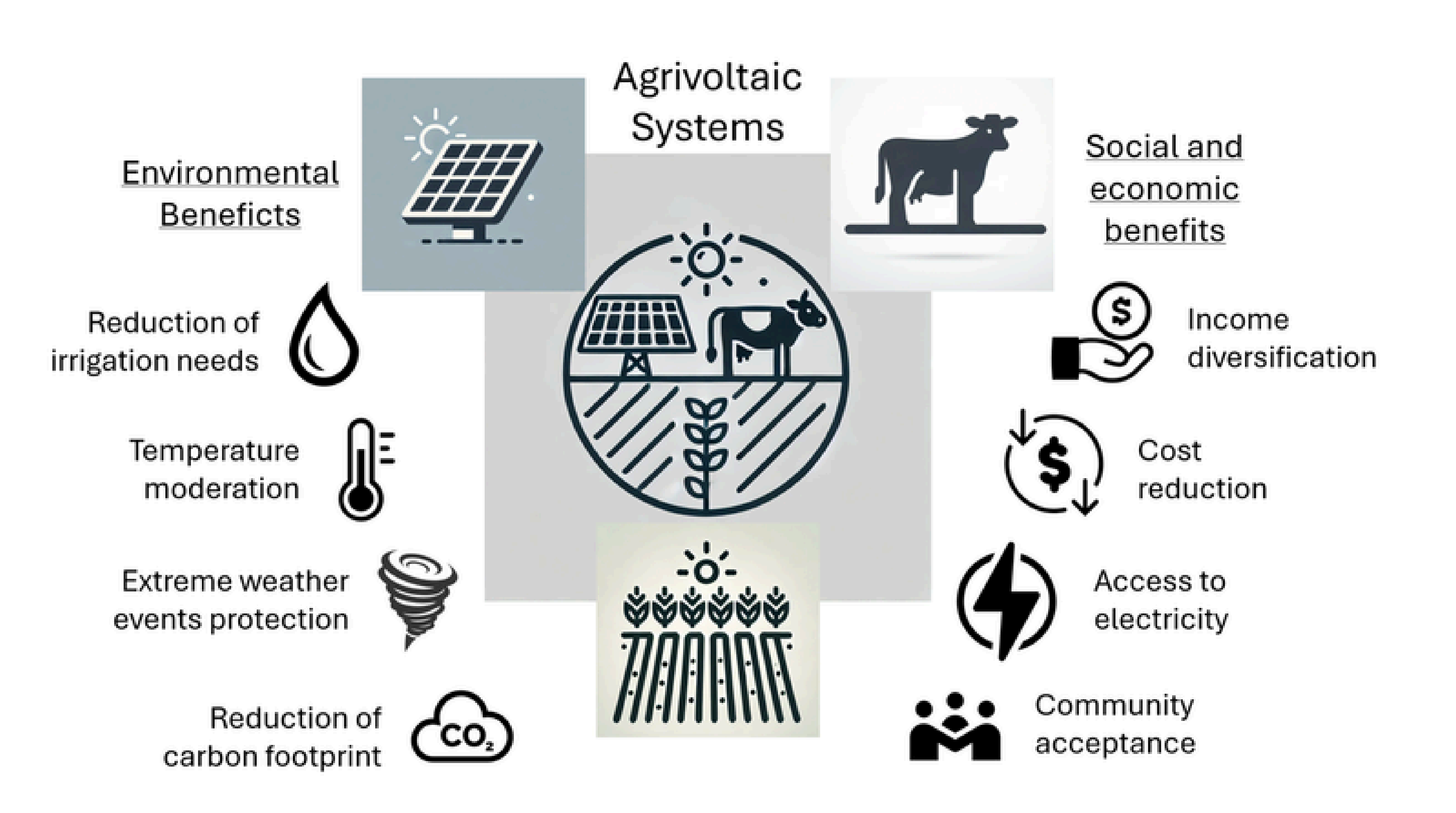
APV System

What: An Agrivoltaics (APV) system is an innovative technology that allows land to be used simultaneously for farming and generating electricity with photovoltaics (Struijker Boudier, von Wels, & Szalay, 2022).

Provides triple-benefit solutions

- Meeting renewable energy targets
- Solving food security challenges
- Addressing water conservation needs

In addition, they also offer job and educational opportunities for the impacted communities



Benefits in Relation to Agriculture

1. **Cooling:** Plants transpiration can cool the panels and protect them from overheating (Struijker Boudier, von Wels, & Szalay, 2022). In return, crops are protected from extreme heat
2. **Water Conservation:** A more humid and cool environment, reducing the amount of water needs by plants

Midlet, Morocco

Where: Midelt, located at about 1,500 meters above sea level

- Central highlands between the Middle and High Atlas Mountains,
- Semi-arid to cold-arid climate with long, cold winters and short, hot summers
- The proposed 15-hectare agrivoltaics pilot site is in Amersid, east of Midelt,
  - Soil characteristics ideal for crops such as apples, durum wheat, and barley
  - Leading apple-producing region due to its favorable high-altitude conditions
    - while cereals—especially wheat and barley—remain vital
- Water scarcity and challenges on the rise, agriculture relies on snowmelt, canals, and groundwater

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Opportunities vs Risks

The report highlights three main opportunities and risks identified in implementing an APV system in Midlet, Morocco for Benmore Energy

1. Contributing to Morocco's ambitious solar energy goals
2. Finding solutions to food scarcity and water conservation practices
3. Engaging, educating and positively impacting the local community

1. The impacts of climate change (depleting water sources)
2. System performance challenges (system optimization, shading vs light vs performance)
3. Financial uncertainties

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Recommendations

1. CROP SYSTEMS SELECTION
2. SUSTAINABLE IRRIGATION
3. COMMUNITY ENGAGEMENT

Crop System(s) Selection

Crop Selection: Select one of the following crops or crop systems to plant under the solar panels

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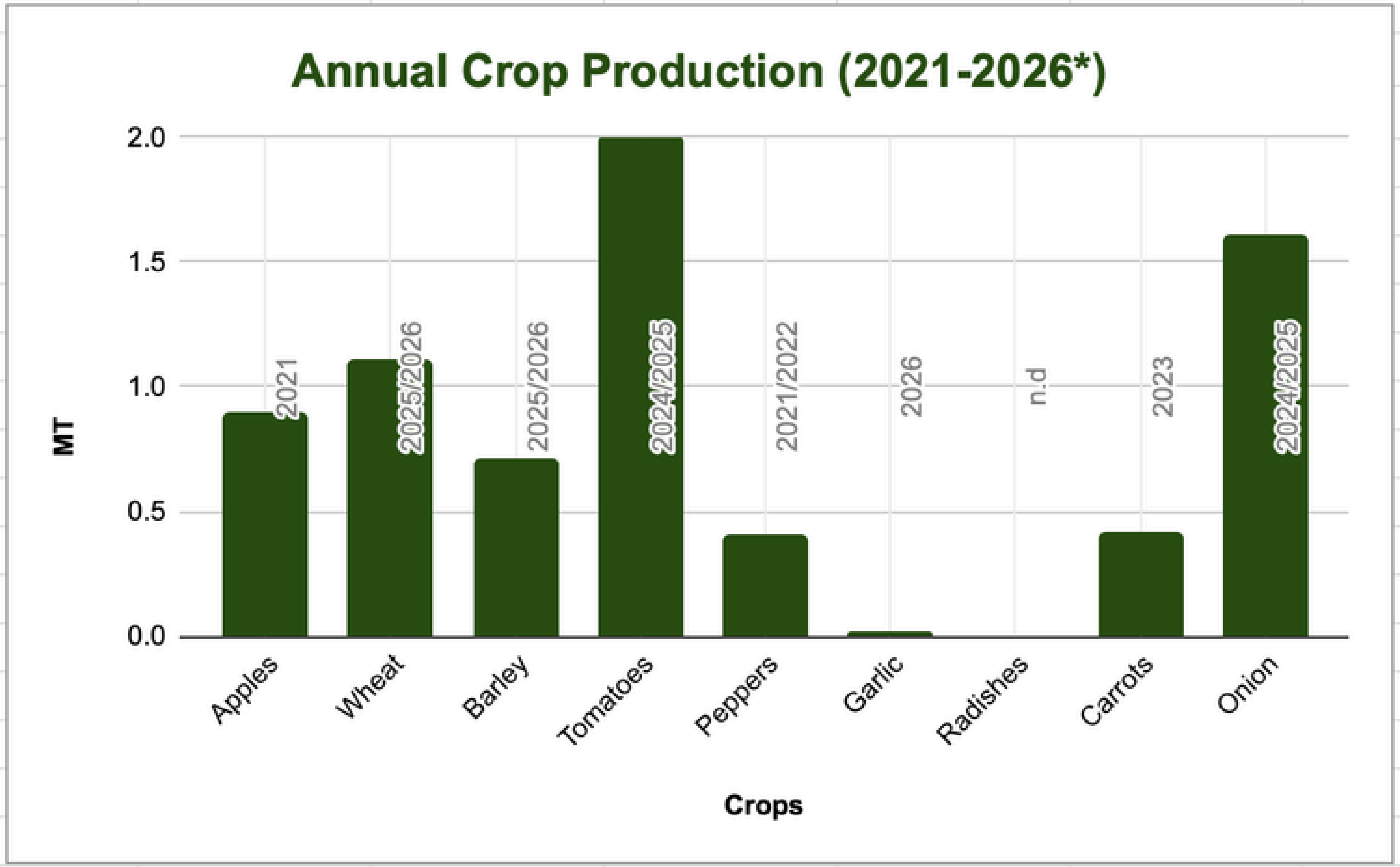
CROPS OVERVIEW

The following crop recommendations include single crop options or mixed crop systems:

- **Mixed Crop Group #1:** Tomatoes, Pepper, Garlic
- **Mixed Crop Group #2:** Carrots, Radishes, Onions
- **Cereals:** Durum Wheat and Barley
- **Apples**



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LAND FOR FARMING: GCR

GCR: Ground Cover Ratio determines how much land is dedicated for solar panels vs for crop

This project tests a 15ha solar capacity, with a GCR of .36 =

***9.6 ha agricultural capacity

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1.Mixed Crop Group #1 & #2

Mixed crop systems—organized into two companion-planting groups—are recommended.

Mixed Crop Group #1


Tomatoes
Peppers


Garlic

Mixed Crop Group #2


Carrots

Radishes

Onions

- Group 1: garlic naturally repels pests, prevents fungal diseases, and improves soil health, benefiting tomatoes and peppers, which share similar growth and nutrient needs
- Group 2 :onions deter pests that target carrots, while fast-growing radishes loosen the soil, creating ideal conditions for carrot root development
- All selected crops are already familiar to local farmers, culturally important in Moroccan diets, perform well under shading/partially shading conditions and provide mutual benefits that enhance overall yield quality and quantity

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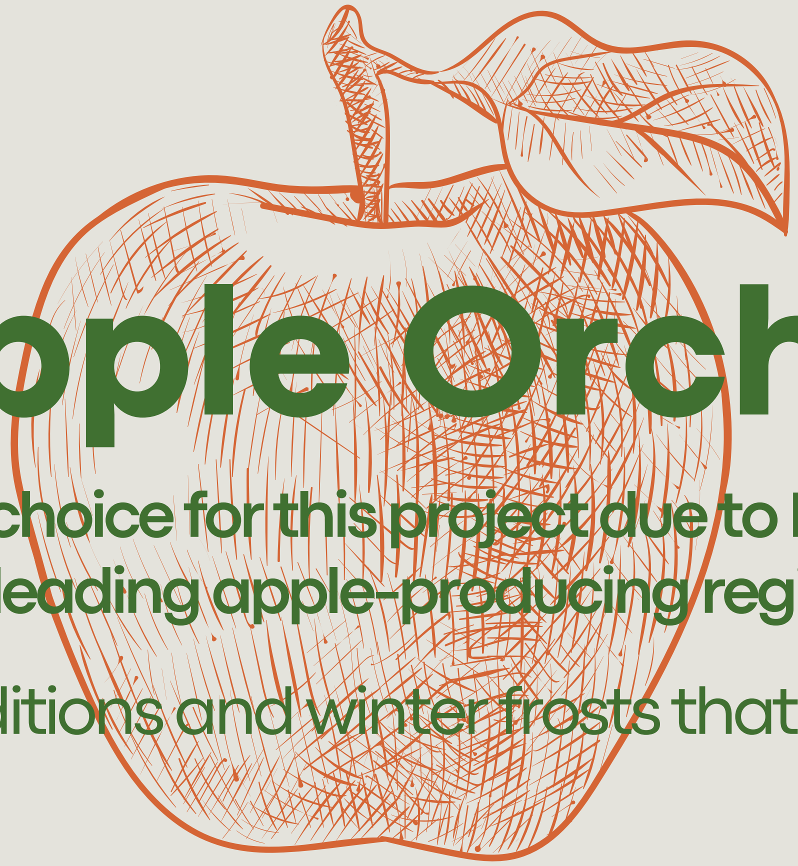
2.Cereals: Durum Wheat & Barley

Widely grown in Midelt region, are vital in Moroccan cuisine and as fodder for livestock

- Climate stress and recurring drought have significantly reduced national cereal yields—by nearly 69% in recent years—yet demand for wheat and barley remains high, forcing Morocco to rely heavily on imports
- Durum perform well under partial shading from solar panels
- Research from Spain and Morocco, including work with ICARDA, shows that both crops can increase grain yield under solar panels and that newly developed heat- and drought-tolerant varieties can further strengthen performance
- Growing cereals beneath the panels can therefore improve local food security, reduce national import dependence, conserve water through shading, and support economic resilience in Midelt and beyond



3.Apple Orchards

Apples remain a strong crop choice for this project due to Midelt’s reputation as Morocco’s leading apple-producing region

- Supported by high-altitude conditions and winter frosts that favor varieties like Golden Delicious and Starking
- Although climate change has created yield instability, production has not declined enough to justify abandoning apple cultivation, and research shows promising performance under agrivoltaic systems
- Case studies from southern France and southern Germany demonstrate that solar panels can create beneficial microclimates—cooler temperatures, higher humidity, and improved water conservation—while still allowing apple trees to receive 80–90% of required light
- Although some shading can reduce photosynthesis and slightly lower yields, the combination of energy production and profitable apple output makes apples suitable for APV systems
- Ongoing pilot agrivoltaics projects at Cornell and Washington State University further highlight the growing potential of pairing apples with solar panels for scalable, climate-resilient production.

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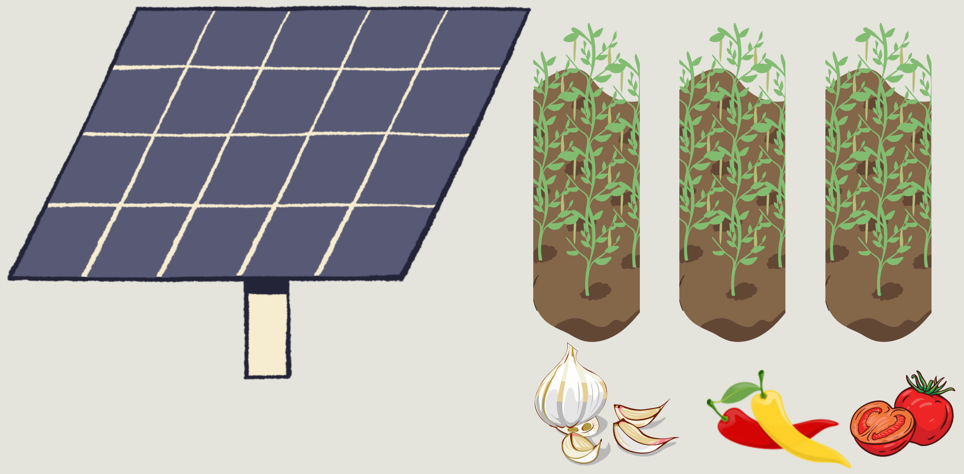
Technical Specifications

Crops	Min-Max Plant Height Growth (cm)	Minimum Mount Height (cm)	Min - Max Mount Height in Meters	Spacing Between Rows	Spacing Between Crops
Apples	300 - 500 cm	575 cm	6 m	4 m	60 - 90 cm
Cereals (Wheat and/or Barley)			**2 m**	**.25 m**	**8 cm**
Durum Wheat	86 - 93 cm	107 cm	2 m	.25 m	
Barley	60 - 120 cm	138 cm	2 m	.25 m	
Mixed Crop Group #1			**4 m**		
Tomatoes	200 - 300 cm	345 cm	4 m	1 - 1.5 m	45 - 91 cm
Sweet Peppers	30 - 76 cm	88 cm	1 m	1 - 1.5 m	30 - 90 cm
Garlic	30 - 60 cm	70 cm	1 m	15 - 20 cm	15 - 20 cm
Mixed Crop Group #2			**1 m**		
Carrots	30 - 60 cm	70 cm	1 m	30 - 45 cm	5 -8 cm
Radishes	15 - 45 cm	52 cm	1 m	7- 15 cm	3 - 5 cm
Onions	n/a	n/a	1 m	15 - 20 cm	30 - 45 cm

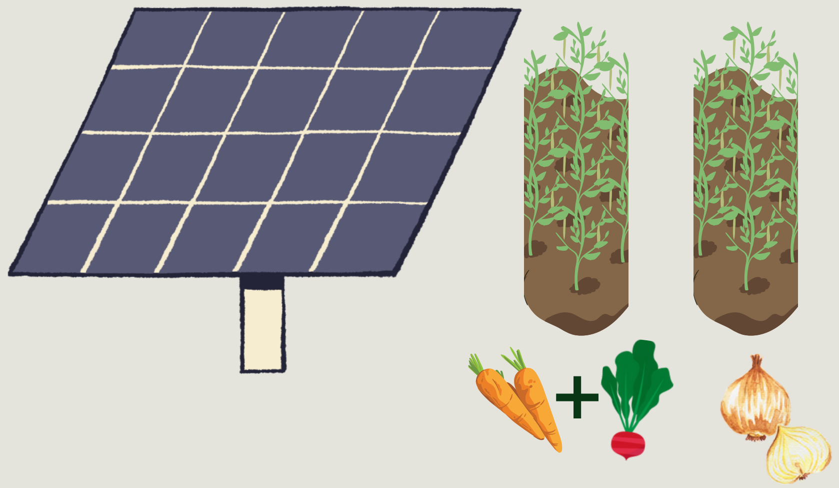
Technical Specificatins Continued

Mixed Crop Group #1 : Tomatoes, Peppers and Garlic



Tomatoes: Furthest away from the panel (3rd row), requires the most sunlight.
Peppers: In the middle row, can be near tomatoes - tolerates partial shade
Garlic: Directly under the panels (first row), the most shade tolerant of the group

Mixed Crop Group #2 : Carrots, Radishes and Onions



Carrots & Radishes: Carrots and radishes are shade tolerant and can be sowed in the same row since radishes will sprout first, breaking the soil and improving its condition in time for the carrots to sprout.
Onions: grown in parallel to the carrots and radishes, close enough to help deter pests such as carrot mites.

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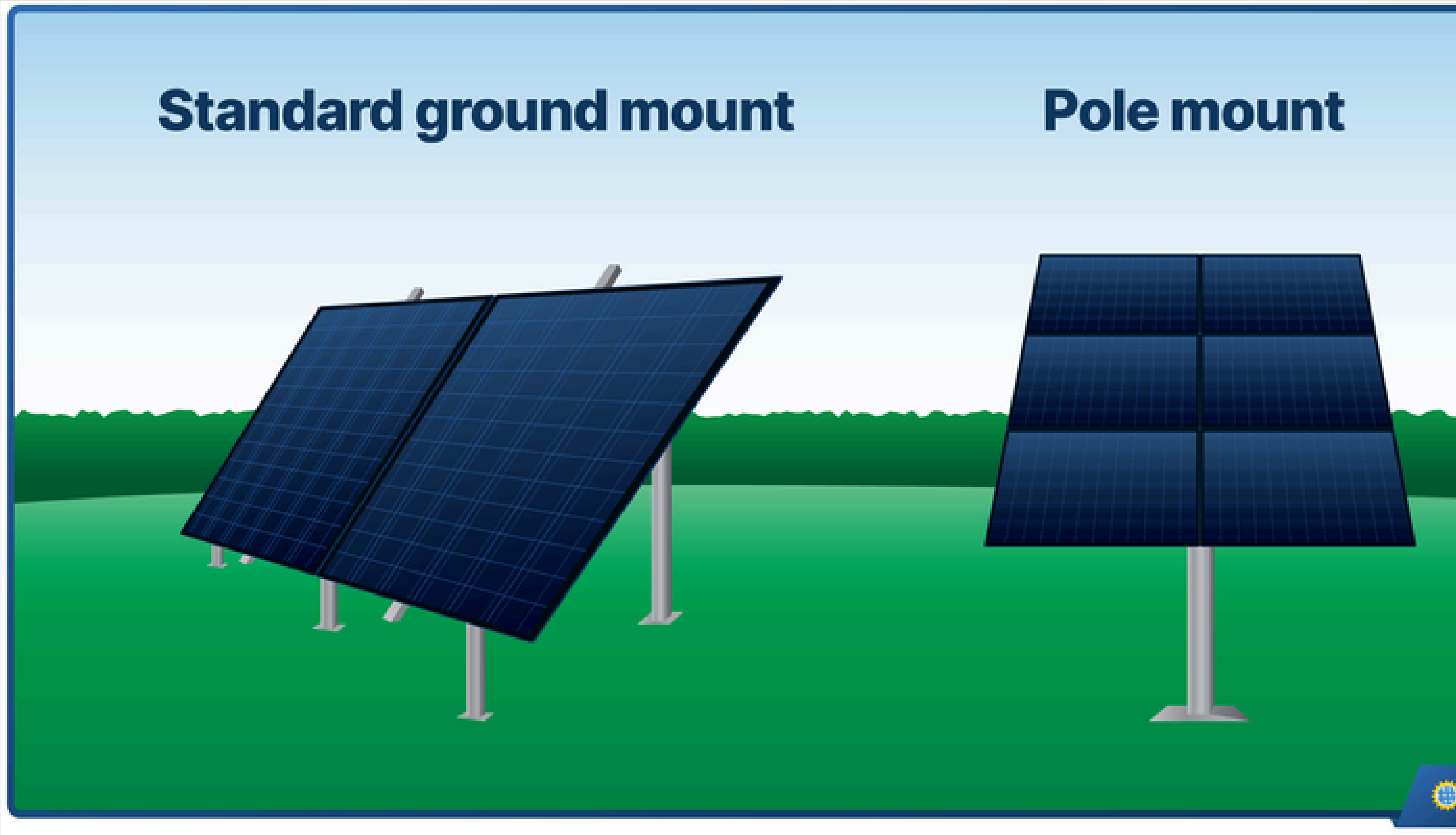
Technical Specifications Continued

Mounting Alternatives



- Traditional ground mounts are cheaper and commonly used
- Pole-mounted systems are recommended
  - Reduce soil disturbance
  - Free up more space for crops,
  - Allow for future upgrades to tracking without costly reconstruction

- Key panel specifications—tilt angle, orientation, spacing, and mono- vs. bifacial design—will also influence both energy production and crop performance
  - A tilt of about 30–33° is commonly used in Morocco
  - Increasing spacing between rows can improve light distribution to crops beneath the panels

- Although monofacial panels are cost-effective, bifacial modules could capture additional reflected light and enhance overall system output, making them worth evaluating for the APV design.

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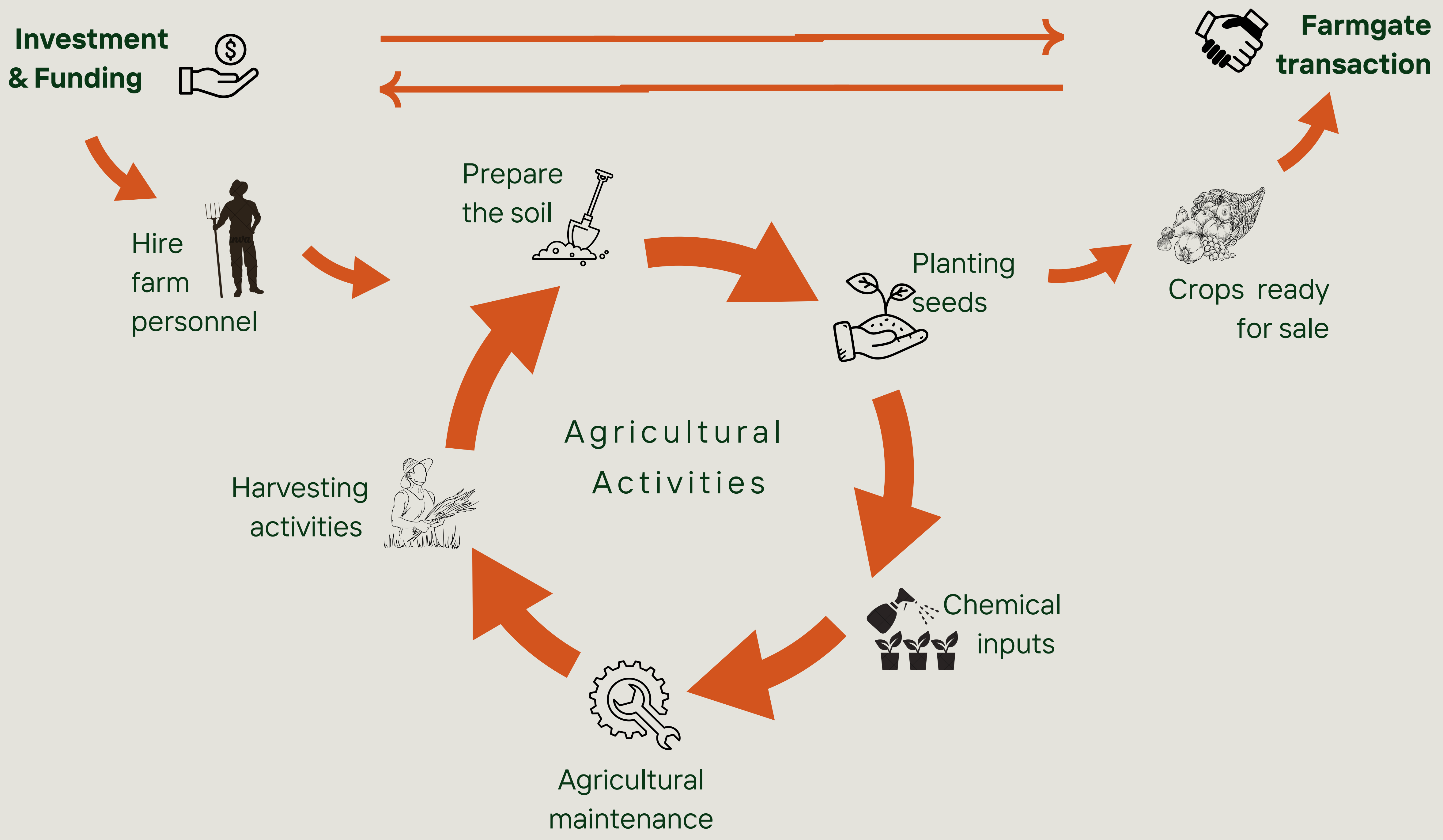
Business Life-Cycle Analysis

Agriculture: Business Life Cycle Assessment



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Cost-Benefit Analysis

Crop System	Gross Revenue	Variable Costs	Net Cash Flow	ROI
Mixed Crop Group #1	$3.8M	$760K	$3M	400%
Mixed Crop Group #2	$6.8M	$600K	$6.2M	981%
Cereals	$310K	$159K	$150K	95%
Apples	$2.5M	$780K	$1.7M	220%

- Analysis of years 2–10 shows strong profitability across all crop groups when comparing farm-gate revenues to CAPEX + OPEX (seeds, labor, fertilizers, chemicals, and supplies).
- Cost models for each crop were built using a detailed worksheet outlining all assumptions, escalations, risks, and data sources
- Net cash flow remains positive for all systems, demonstrating solid long-term financial potential for the project.

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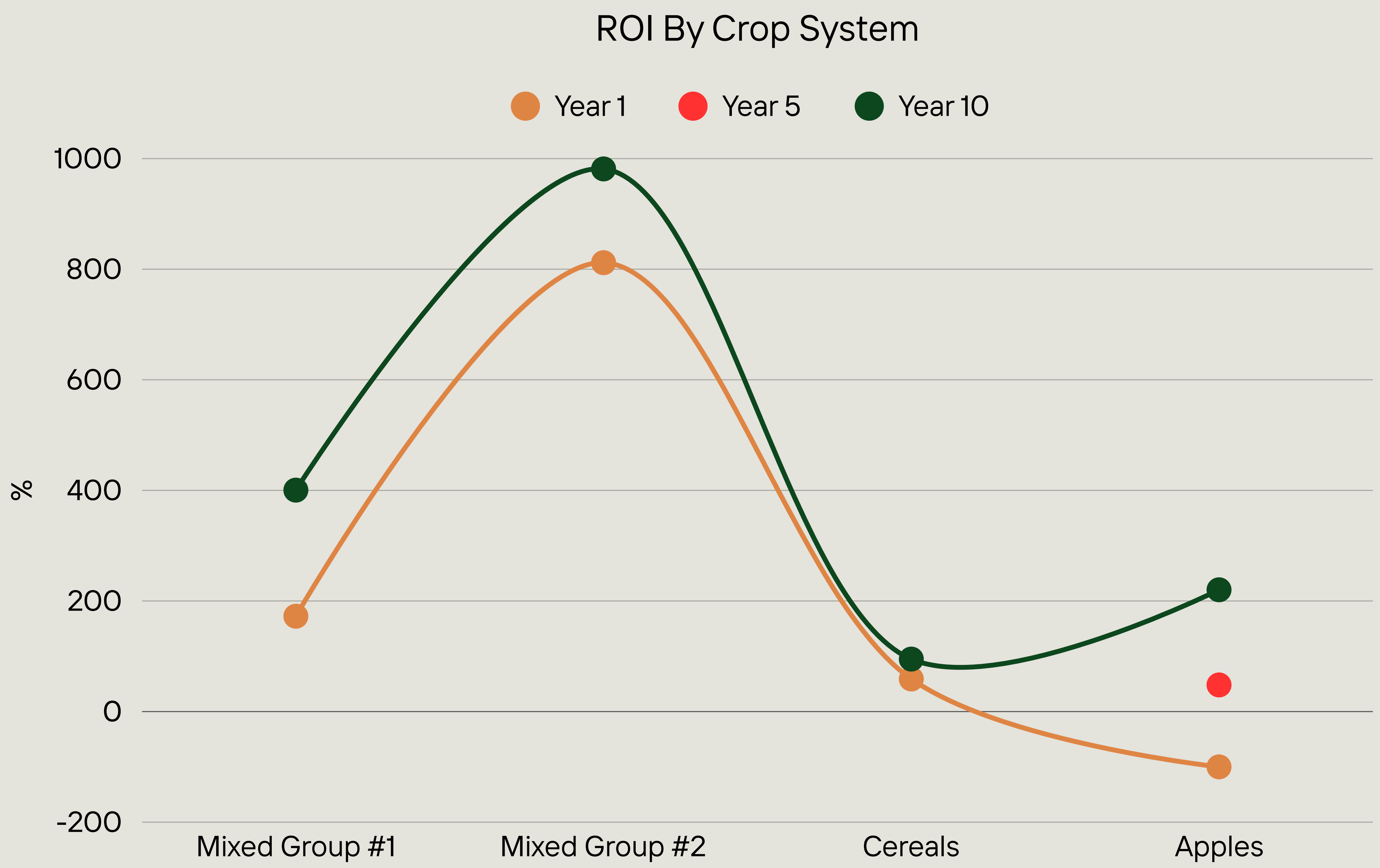
Return on Investment (ROI)



- Crop systems with shorter growth cycles—cereals and both mixed-crop groups—generate ROI in the first year because they mature within 28–270 days.*
- Apple trees require 3–5 years to produce fruit, so the model assumes no profitability until Year 5, after which ROI increases steadily.
- Year-1, Year-5, and Year-10 performance comparisons highlight how crop maturity timelines drive differences in financial outcomes

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Shade - Cost Matrix

Crop System(s)	Tolerance Under Shading (PVs)	Profitability
Mixed Group #1	Least	High
Mixed Group #2	**Moderate**	**High**
Cereals	Most	Low
Apples (Orchard)	**Moderate/ Conditional**	**Low/High**

Sustainable Irrigation System

Drip Irrigation System: Invest in the right resources to develop a sustainable irrigation system using solar power

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Solar Irrigation Overview

- Agriculture in Morocco—especially Midelt—is highly vulnerable to water scarcity, forcing many farmers to scale down orchards and shift to lower-water crops
- Farmers rely heavily on the Hassan II (Sidi Said) Dam, but water access is costly and unevenly distributed, with many still using traditional irrigation methods
- The Green Morocco Plan provides 100% subsidies for qualified drip-irrigation projects, accelerating the shift toward water-efficient systems
- In solar-drip systems, ~80% of costs typically come from the solar component, but for this project the PV system is already budgeted—reducing irrigation costs for Benmore.

By investing in the infrastructure to carry out a solar powered irrigation system - specifically a low drip irrigation design - for this project can:

- Reduce water consumption (Assouli et al., 2018) by up tp 47% (Wifaya et al., 2022)
- Increase profitability (Assouli et al., 2018)
- Improve the distribution of water for all crops (Zaharaddeen et al., 2023)
- Incentivize growing high-cash crops (such as apples) (Zaharaddeen et al., 2023)

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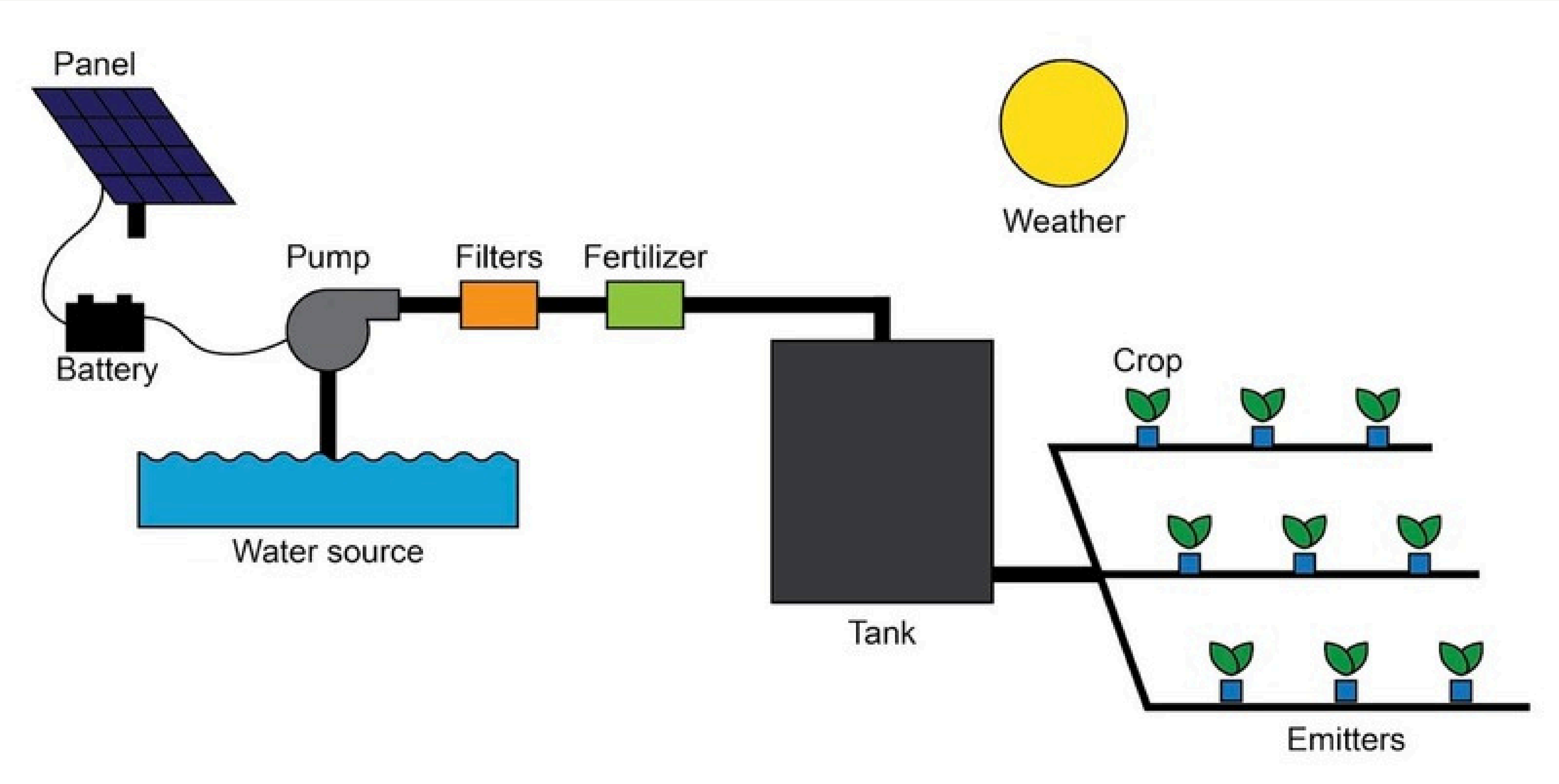
Technical Specifications

- A solar-powered drip irrigation system uses PV energy to run a pump and deliver water through emitters according to crop needs
- Core components typically include pumps, pipes, valves, filters, emitters, and labor, but each site requires a customized design
- For this pilot project, extra elements—such as batteries for energy storage, appropriately sized water tanks, and automated controls—are needed to ensure reliable irrigation performance



Cost Analysis

Initial Investment, Operating & Maintenance Costs for Year 1

	Average Cost	10% Risk - 5% Sensitive	15% Risk - 7% Sensitive	20% Risk - 10% Sensitive
CAPEX + Risk	$35,503	$39,053	$40,828	$42,604
OPEX + Sensitivity		$2,953	$3,858	$5,260
Deployment + 1st Yr O&M	**Total:**	**$42,006**	**$44,686**	**$47,864**

Recurring Operating & Maintenance Costs (Year 2 - Year 10)

Recurring O&M	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Total**
Low (5%)	$3,100	$3,255	$3,418	$3,589	$3,768	$3,957	$4,155	$4,362	$4,581	$34,186
Medium (7%)	$4,051	$4,253	$4,466	$4,689	$4,924	$5,170	$5,429	$5,700	$5,985	$44,667
High (10%)	$5,523	$5,800	$6,090	$6,394	$6,714	$7,049	$7,402	$7,772	$8,161	$60,904
Average	**$4,225**	**$4,436**	**$4,658**	**$4,891**	**$5,135**	**$5,392**	**$5,662**	**$5,945**	**$6,242**	**$46,586**

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Benefits Analysis

- Reduce water consumption
- Eliminate electricity bills from expenditures
- Increase water efficiency and distribution
- Reduce water costs
- Opportunity for innovative modifications to improve performance

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Future Recommendations

- Community Engagement
- Revisiting Crop Recommendatins
  - SME Inputs
  - Advanced Software and Tools for feasibility simulations + costs
- Collaborating with water SMEs in the region on irrigation planning and design
- Engaging with solar panel design team for potential modifications

- ***Start small, start smart, invest in knowledgeable people who are on the ground. Leave room for trial & error and learn from them.***


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Thank You