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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

Applicazione del LCA alle filiere agro-alimentari

Missione 4 Istruzione e Ricerca

Il Life Cycle Thinking applicato ai sistemi idroponici: il caso studio del Progetto "FUD-OF-SITHY

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Favor the **U**rban **D**evelopment **OF** **S**ustainable agr**I**culture **T**hrough **Hy**droponics

FUD-OF_SITHY

Milano 23 Gennaio 2026

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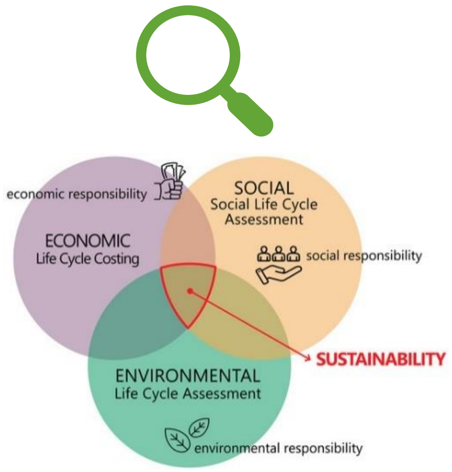
Project PRIN 2022 PNRR: FUD-OF-SITHY - Favor the Urban Development OF Sustainable agrIculture Through Hydroponics

(European Union- Next Generation EU, Mission 4 Component 1, P2022F9HEW)

Goal: develop hydroponic agriculture as a soil-free cultivation system on the roofs of buildings as an alternative method for obtaining sustainable food in cities in the Mediterranean context, taking into account environmental, energy, economic, and social aspects.



- To define strategies for the creation of hydroponic systems with reduced environmental impacts
- To assess economic and social aspects of hydroponic systems
- To assess the contribution of these systems to the buildings thermal insulation

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What is hydroponics?

Hydroponics is a nutrient-enriched water cultivation that promotes lower water consumption, efficient use of space, precise nutritional control and higher yields.

HGRS represents a potential innovative solution to current agricultural processes, to be applied especially in the urban context, involving an alternative cultivation technique that does not use soil.

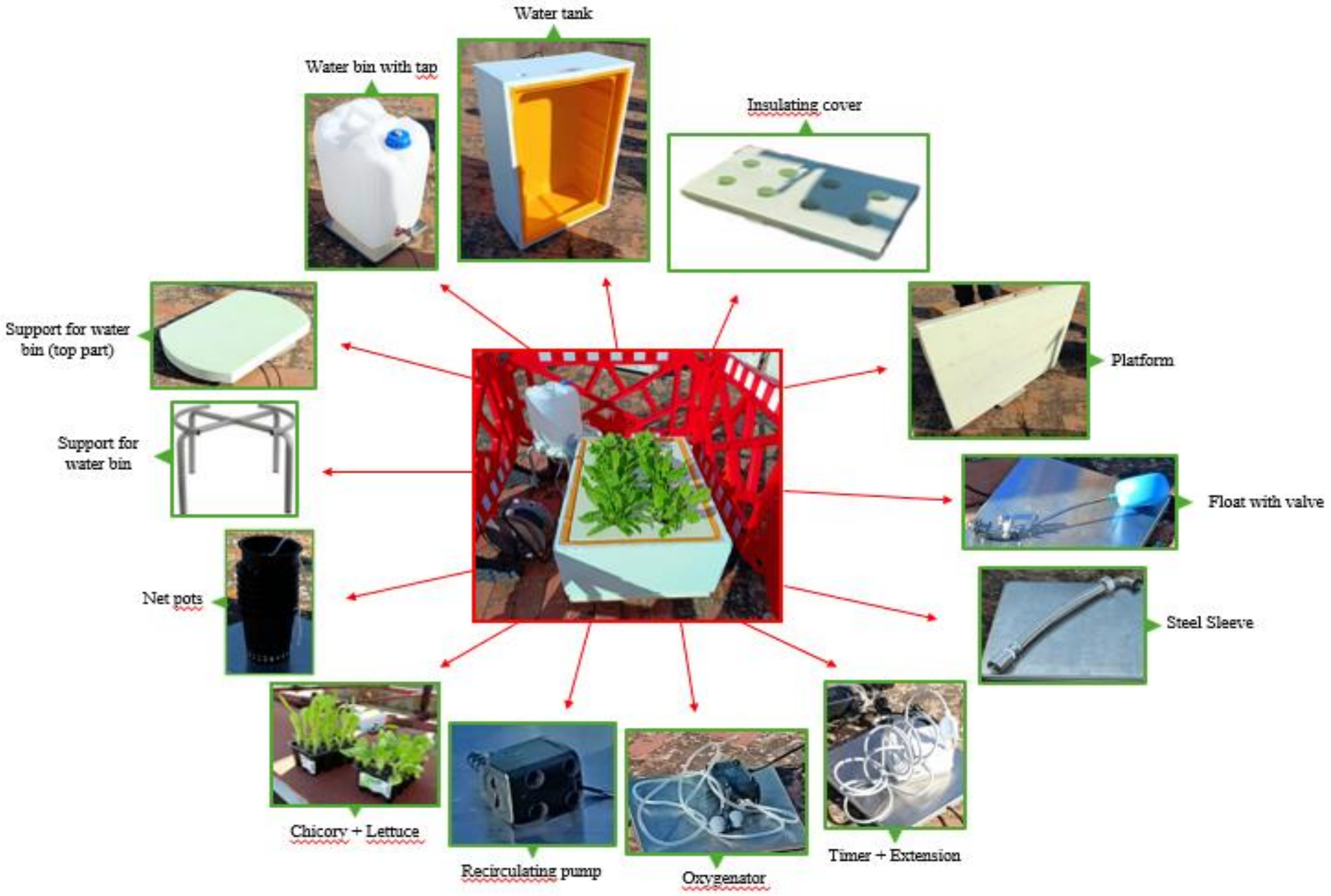
Prototype development and crops analysis

UNIPA

UNIRC

UNICT

Description of the Syste



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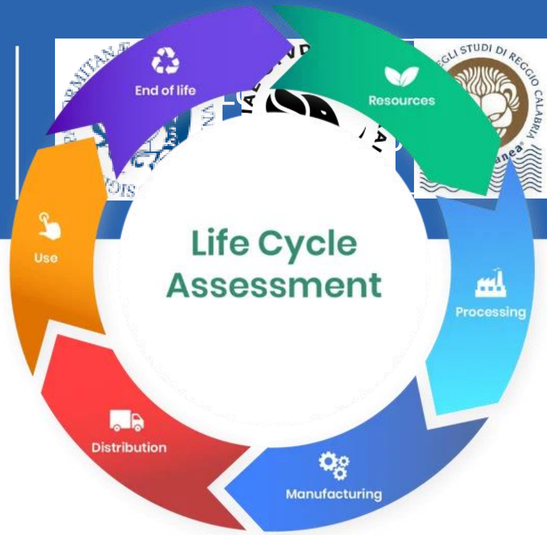

Environmental analysis

Goal: to assess the potential impacts of the HGRS system, identifying the life cycle stages/components with the highest environmental impact and providing guidance to enhance the system's sustainability.

The functional unit chosen is the entire HGRS system.

A **cradle-to-gate approach** was adopted, including:

- **Extraction** and processing of raw materials;
- **Transport** of the raw materials from the site of extraction to the site where the system components are produced;
- **Manufacturing** of the system components, including energy consumption and ancillaries;
- **Manual assembly** of the hydroponic system: step directly examined during the installation process.

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Primary data collected were related to the components of the hydroponic system, taking into account:

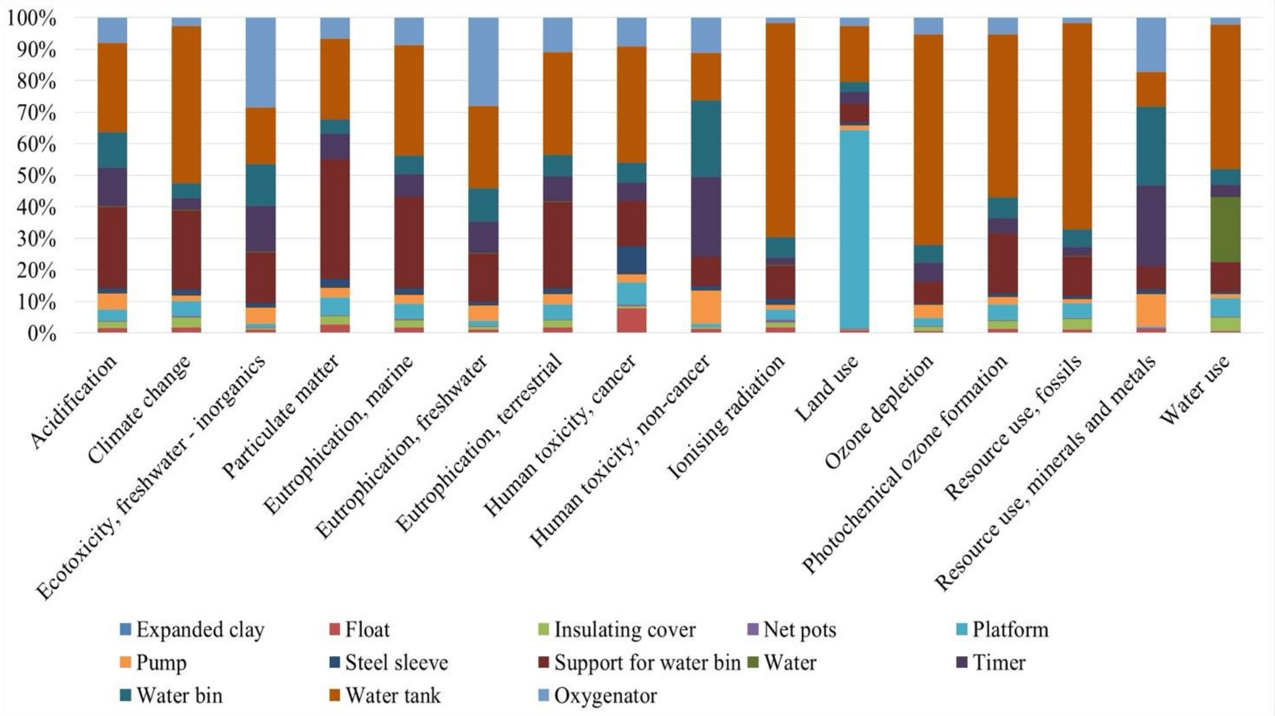
- **Total mass** of the component;
- **Identification** of each **subcomponent** and related **material/s** and **mass**;
- **Length** of electric cables.

Secondary data were selected in the environmental database Ecoinvent.

Component	Material	Mass (kg)	Length (m)
Water tank - Inner part	Polyethylene	10.90	
Water tank - Outer Part	Polystyrene	0.84	
Insulating cover	Polystyrene	0.65	
Platform	Wood	4.70	
	Polystyrene	0.70	
Water bin	HDPE	0.90	
Tap	Brass	0.10	
Pump	Mixed materials	0.20	
Pump (electric cable)			1.45
Oxygenator	HDPE	0.05	
	ABS	0.08	
	Copper	0.08	
	Steel	0.04	
	PVC	0.06	
	Air stones	0.03	
	Silicone		
Oxygenator (electric cable)			1.37
Timer	Polycarbonate	0.03	
	ABS	0.16	
Timer (electric cable)			2.93
Water bin support	Aluminium	2.05	
	Polystyrene	0.20	
Float	HDPE	0.03	
Valve	Stainless steel	0.17	
Net Pots	PET	0.15	
Steel sleeve	Stainless steel	0.20	
Substrate	Expanded clay	0.15	

Results of the environmental analysis

Impact category	Unit	Total
Acidification	mol H+ eq	4.67E-01
Climate change	kg CO2 eq	7.86E+01
Ecotoxicity, freshwater - inorganics	CTUe	5.07E+02
Particulate matter	disease inc.	3.81E-06
Eutrophication, marine	kg N eq	7.09E-02
Eutrophication, freshwater	kg P eq	4.03E-02
Eutrophication, terrestrial	mol N eq	7.64E-01
Human toxicity, cancer	CTUh	3.72E-07
Human toxicity, non-cancer	CTUh	1.91E-06
Ionising radiation	kBq U-235 eq	8.62E+00
Land use	Pt	8.66E+02
Ozone depletion	kg CFC11 eq	2.36E-06
Photochemical ozone formation	kg NMVOC eq	3.58E-01
Resource use, fossils	MJ	1.70E+03
Resource use, minerals and metals	kg Sb eq	2.39E-03
Water use	m3 depriv.	4.58E+01



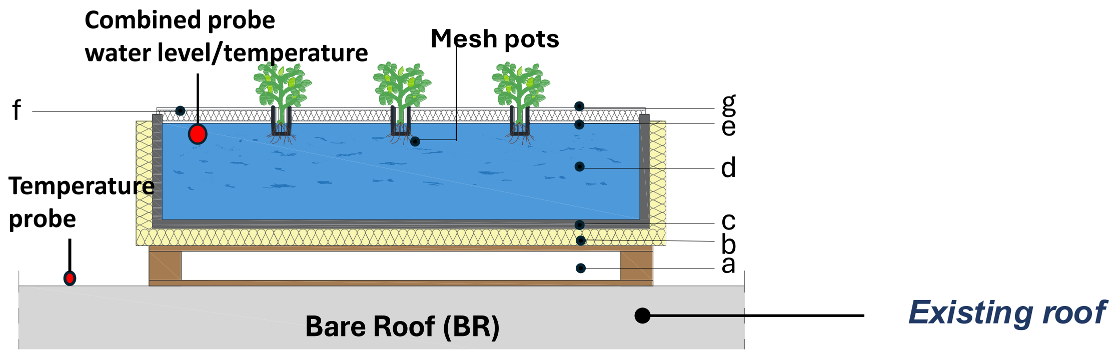
Main hot-spot: water tank (use of PE); Oxygenator (use of copper); Platform (use of wood); Support for water bin (use of aluminium); Timer (use of cable) and water bin (use of brass).

Energy analysis

Goal: to <u>assess the thermal behavior of hydroponic roofs in Mediterranean climates</u>, where such systems could play a crucial role in improving building energy efficiency.

address the research gap by presenting experimental data from a prototype of a **novel modular hydroponic roof system,** designed for retrofitting flat roofs, **tested in Catania**, Italy.

Experimental data and **a validated TRNSYS simulation** model has been used to assess **the impact of the hydroponic system on rooftop surface temperature reduction**.



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Energy analysis

Experimental measurements campaign

A weather station placed on top of a building in front of the experimental site, has been used to collect meteorological data required for the implementation of the TRNSYS simulation model.

Sensor		Accuracy	Resolution	Measurement range
Air Temperature	To	± 0.3 °C	0.1 °C	-40 ÷ 60 °C
Relative Humidity	RH	± 2%	1%	1 ÷ 100%
Anemometer – wind speed	w	± 0.9 m/s	0.4 m/s	0 ÷ 89 m/s
Anemometer - wind direction	ϴ	± 3°	1°	1 ÷ 360°
Rain gauge	r	± 5% up to 250 mm/hr	0.1 mm/hr	1 ÷ 762 mm/hr

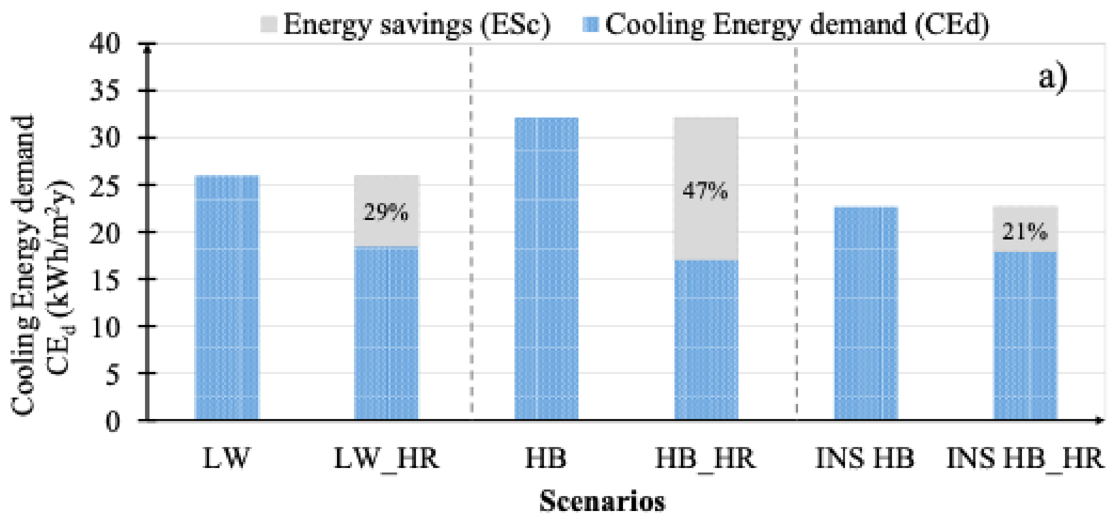
In-situ temperature measurements of both the water within the hydroponic module and the roof external surface were collected using a wireless node

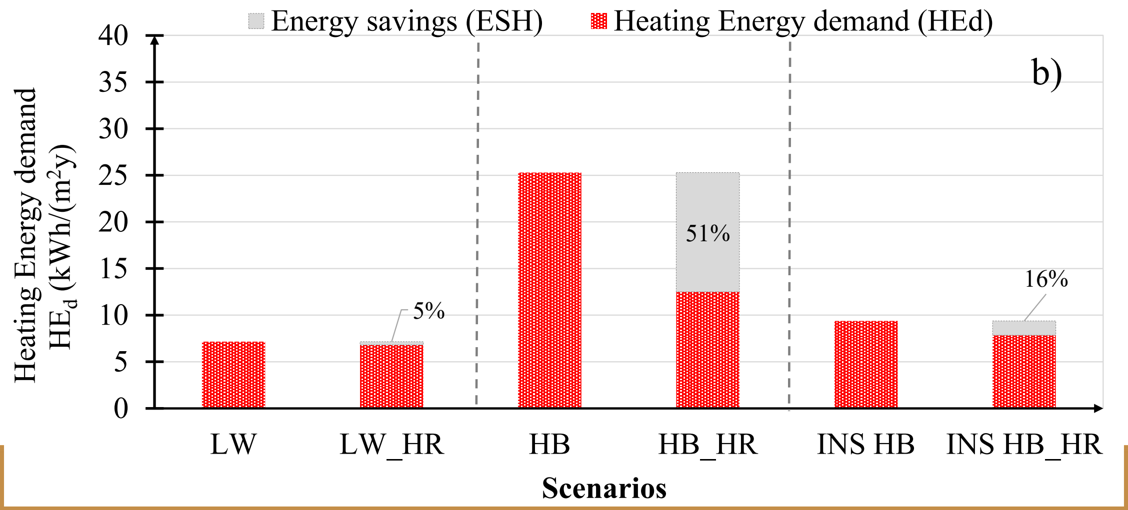
Sensors	Parameter		Accuracy	Resolution	Measurement range
Multi-functional probe	Water depth	t_w	± 0.05 m	-	0 ÷ 11 m
	Water Temperature	T_w	± 0.1 °C	0.01 °C	-50 ÷ 100 °C
	Thermal conductivity of the water	λ_w	-	0.1 µS	5 ÷ 100000 µS/cm
Probe for surface Temperature	External surface temperature of the existing bare roof	T_{os}	± 0.1 °C	0.1 mm/hr	-50 ÷ 100 °C

- The **experimental results** obtained during a summer month demonstrated that **the hydroponic module significantly lowers rooftop surface temperatures compared to a conventional bare roof**. The module stabilizes **water temperature between 24.0 °C and 29.0 °C**, even under peak summer heat conditions.

Energy analysis

Thermal energy needs per unit of net floor area: a) Cooling; b) Heating.





- **Scenario HB**: external walls made of Poroton blocks (W_HB); roof realized with a reinforced concrete slab and hollow clay blocks (R_HB).

This scenario represents the actual constructive configuration of the sample room.

- **Scenario INS HB:** the same as Scenario HB but with the addition of a thermal insulation layer in both the external walls and the roof **in order to comply with the current Italian building codes.**
- **Scenario LW**: both external walls and the roof are made of insulated lightweight sandwich panels.

This scenario explores the use of the hydroponic system in well-insulated lightweight structures.

The simulated (TRNSYS MODEL) energy needs for space conditioning show that the hydroponic roof provides a dual benefit in both cooling and heating seasons.

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Economic and social analysis

Goals:

To assess the overall costs generated throughout the life cycle of the system, including capital costs, operating costs during the production, operation, maintenance, and replacement steps. **Life Cycle Costing (LCC) methodology [ISO 15686]**

To assess the social impacts of the hydroponic system throughout its life cycle, according the defined system boundary. **Social hot-spot method** (Risk-Based Approach)

To identify the lifecycle stages/components with the highest economic and social impacts.

The following steps were included:

- **Extraction** and processing of raw materials
- **Transport of the raw materials** from the site of extraction to the site where the system components are produced;
- **Manufacturing** of the system components
- **Installation process**: Manual assembly of the hydroponic system.
- **Operation and maintenance**

Functional Unit: 1 Hydroponic plant, considering the lifespan of a module to be 10 years.

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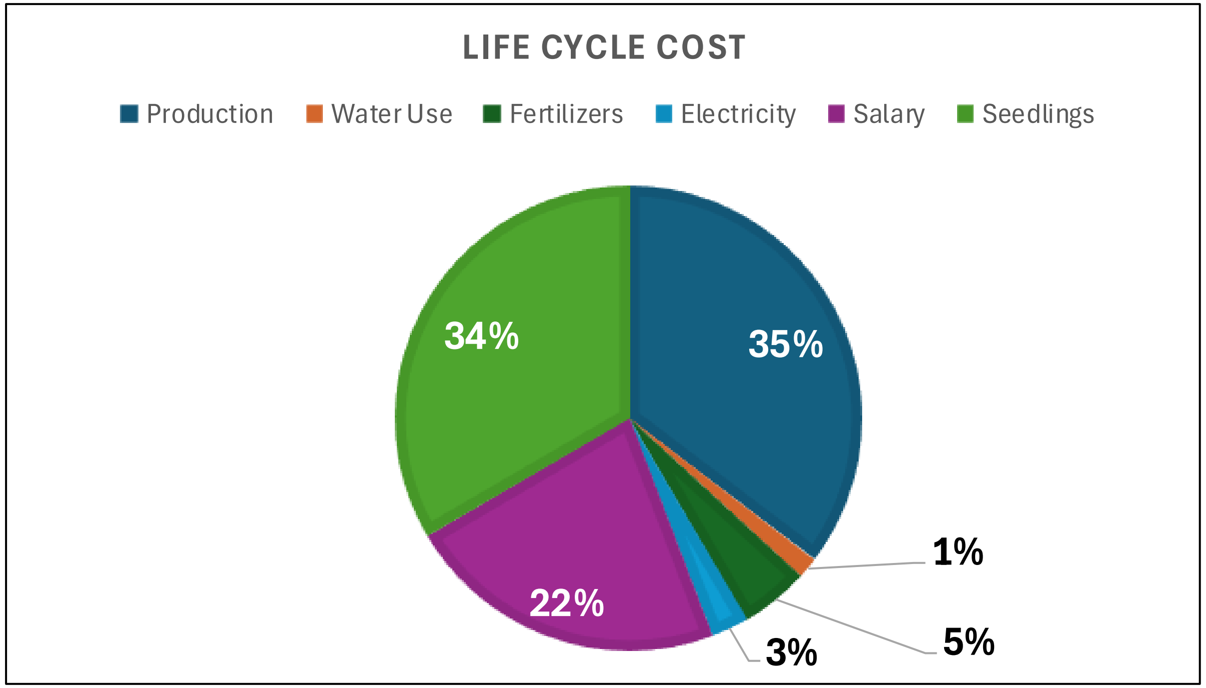
Results: LCC contribution analysis

ITEM	€
Production	-304
Water Use	-13
Fertilizers	-41
Electricity	-23
Salary	-192
Seedlings	-288



Life Cycle Cost = € 860,5

Main cost drivers:

- ❑ Production 35%
- ❑ Seedlings 34%
- ❑ Salary 22%

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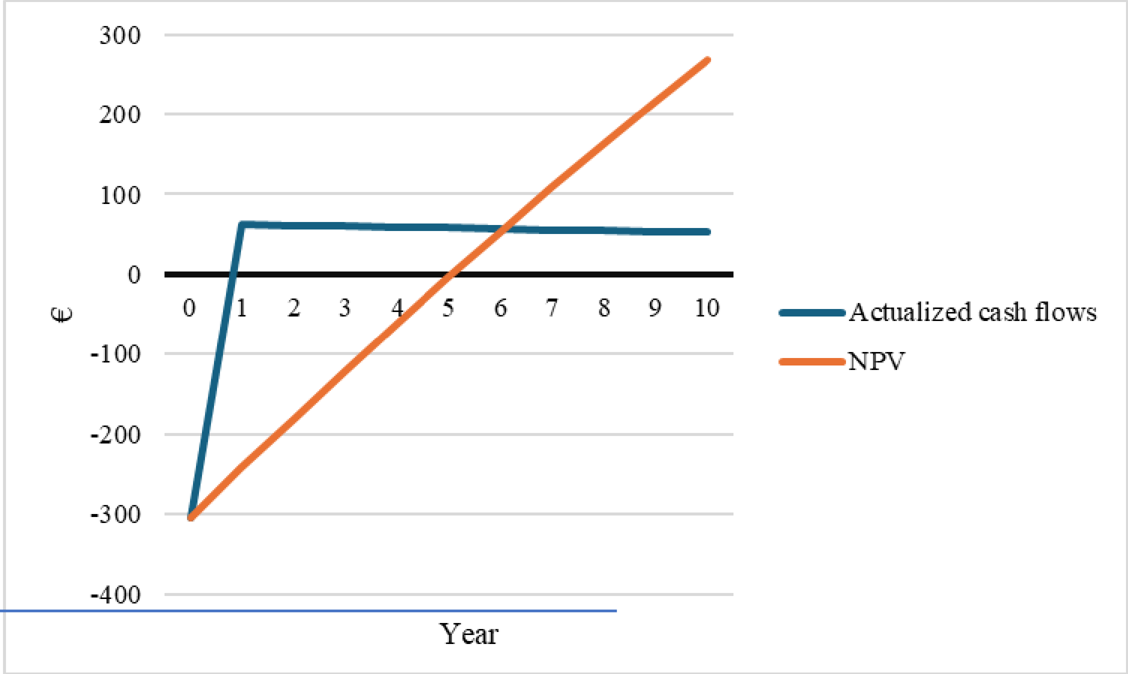
Results: LCC

	€
Revenues	1,194



Net Present Value = € 268.6

NPV > 0 ➡ profitable investment

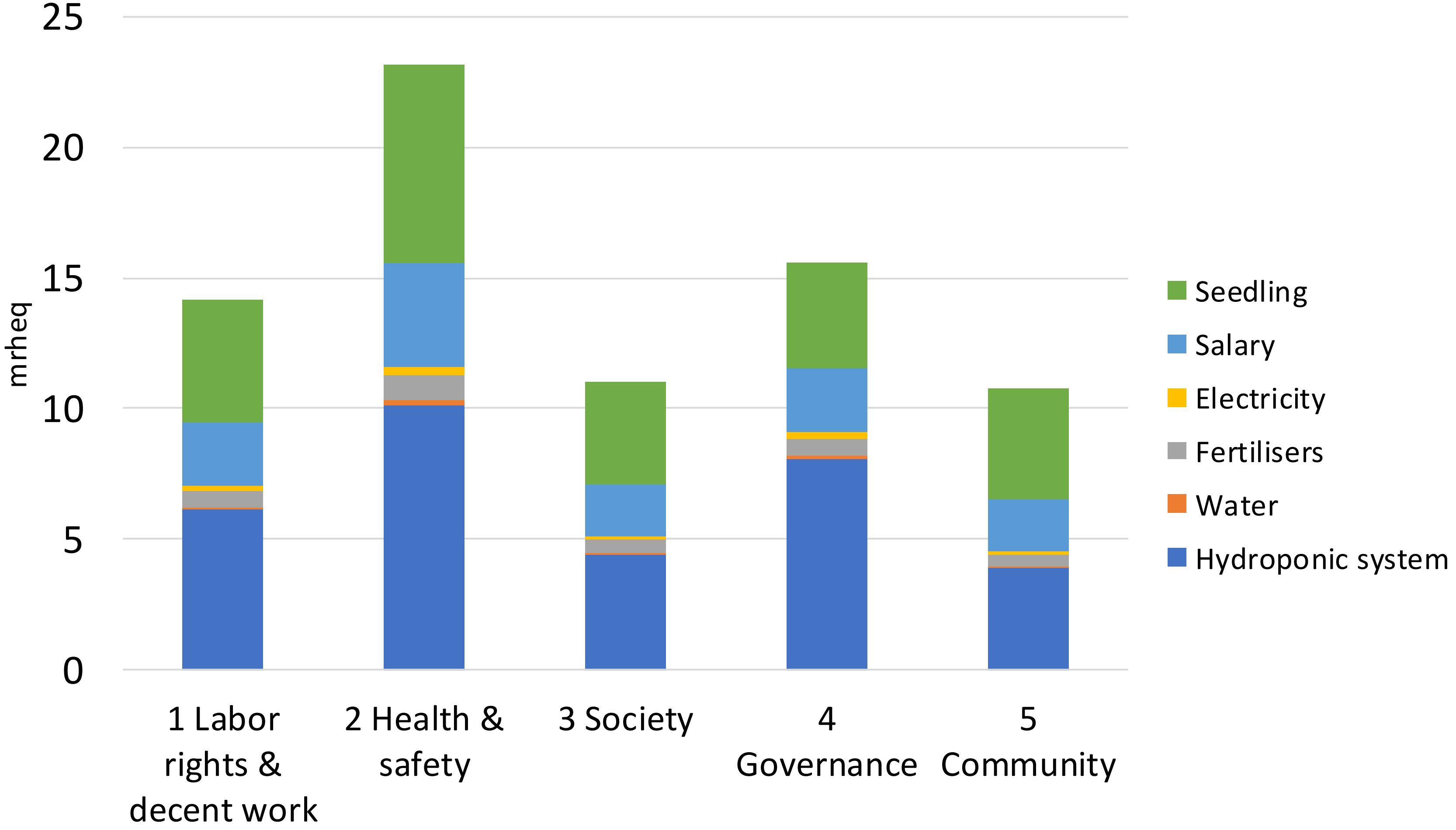
Internal Rate of Return = 16.3%

IRR > discount rate ➡ profitable investment

Benefit/Cost Ratio (BCR) = 1.39

BCR > 1 ➡ profitable investment

Results: S-LCA Contribution analysis



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CONCLUSION

- The study provides a sustainability assessment of the HGRS, offering a fundamental basis for the development of more sustainable urban agricultural systems.
- Environmental analysis: the HGRS's impact is heavily dominated by specific components. Thus, it is important optimizing material choices and design in urban hydroponic systems for enhanced sustainability.
- Energy analysis: the water layer stores incoming heat flux during peak solar irradiance hours and gradually releases it when outdoor temperatures are lower. This effect confirms that hydroponic roof systems can serve as an effective strategy for reducing cooling energy demand and as a promising solution for mitigating the Urban Heat Island (UHI) effect.
- Economic analysis: With a 10-year lifespan the system shows positive indicators. The highest economic hotspots on the life cycle of the module are production, seedlings, and salary.
- Social analysis: The most impacted social categories are Health & Safety, Governance, and Labor Rights. Social hot-spots mirrored the economic ones.

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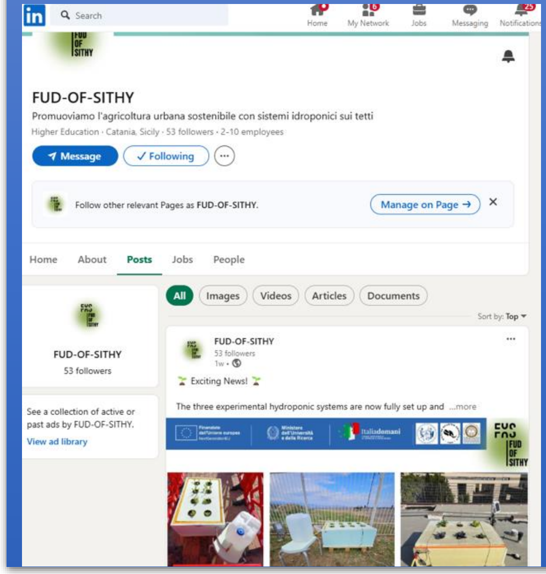

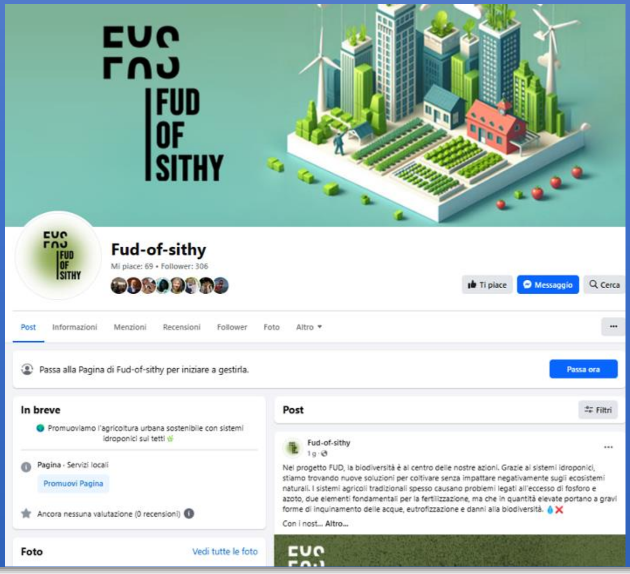

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