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Mioritic Loop: A Smart and Sustainable Closed-Loop Farm Based on Renewable Resources

Mioritic Loop: O fermă inteligentă și durabilă, cu circuit închis, bazată pe resurse regenerabile

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Abstract - The study presents a closed-loop sustainable farm concept that combines photovoltaic energy generation, livestock farming, greenhouse horticulture, and grain agriculture in a year-round, autonomous production model. The system was designed to minimize external inputs and environmental impact while maximizing the efficiency of internal resources. The farm model illustrates how agriculture could transition to a more efficient and self-sustaining system, aligned with the European Union's vision of a greener, climate-resilient future. Furthermore, the model will generate constant capital inflows, promoting a stable and predictable economic environment.

Index Terms - circular economy, closed-loop system, renewable energy, sustainable agriculture.

Introduction

The paper focuses on the concept of a smart and sustainable farm - *Mioritic Loop* - (ML) organized as a closed-loop ecosystem, which means it will provide all of its resources on its own (food, water, and energy) and process waste internally. It will combine efficient resource management, sustainable farming methods and renewable energy sources into an independent and reliable model. In order to balance energy production and consumption with agricultural output, the system will be built to run year-round with minimal external inputs. The topic is part of a larger framework for the agricultural transition to sustainability, in line with European directives on climate neutrality [1], such as the 2413/2023 European Directive (the revised Renewable Energy Directive) and the Fit for 55 legislative packages. The motivation comes from the need to reduce dependence on external resources (fossil fuels, chemical fertilizers) and vulnerability to climate change, by creating an autonomous, efficient, and

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environmentally friendly model. The main objectives are: integrating renewable energy (floating photovoltaic panels), ensuring efficient resource management, valorising waste, and developing a sustainable agricultural cycle that guarantees year-round production, economic resilience, and a positive social impact.

II. METHODS

The proposed model is based on the design of a closed-loop agricultural system that integrates a variety of components: floating photovoltaic panels on the irrigation lake, fixed-point irrigation systems, cereal cultivation, livestock farming, biogas production, and greenhouse horticulture. Each subsystem was examined in terms of its inputs, outputs, and interactions with the farm ecosystem. This methodology includes:

- assessment of renewable energy production potential by simulating solar energy generation using PVGIS;

- assessment of irrigation demand and energy consumption;

-integration of animal waste conversion into bioenergy; (planned for future work)

-design of a greenhouse powered by renewable heat sources (planned for future work).

This systematic approach ensures the autonomous functioning of the farm's production cycle and minimizes external inputs.

The methodological flow of the present study is illustrated in Figure 1, outlining the sequence of steps used to design, implement, and evaluate the Mioritic Loop farm concept.

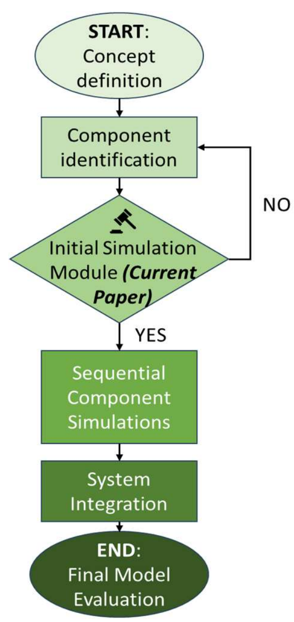

Figure 1. Methodological Flow of the present study

The present paper serves as a feasibility study, analysing just the efficiency of the floating photovoltaic panels (the first module of the farm) in order to decide if the analysis of the sequential components is worth continuing or if the initial component identification should be revised.

A. Site description

The idea came from a farm located in the west of Romania, near Voiteg, Timiș county. The farm has about 500 hectares of agricultural land which is currently irrigated from an artificial irrigation lake, created by the farm owner. Although the system is performing well, it is vulnerable to increasing energy costs and most importantly, climate change, such as the risk of its reservoir drying up due to prolonged drought. Thus, the transition to an autonomous farm model would not only ensure year-round productivity but also reduce the reliance on external energy and water sources. Moreover, it would improve the farm's resistance to environmental challenges, increase resource efficiency and align with global trends in sustainable agriculture, while ensuring long-term economic and environmental friendliness.

B. The proposed farm design and structure

Figure 2. Proposed farm concept. 1-floating photovoltaic panels installed on the irrigation lake, 2-fixed point irrigation system, 3-crop harvesting, 4-livestock farming, 5-biogas plant, 6-greenhouse horticulture

The closed-loop farm concept incorporates various eco-friendly systems to create an autonomous and profitable agricultural environment. Floating photovoltaic panels will be installed on the irrigation lake, harnessing solar energy to power the farm's operations. To increase the system's energy and financial efficiency, the photovoltaic panels will work in combination with the field irrigation systems to produce clean and cheap electricity to power the systems. The harvested crops will bring financial gains to the business and will also serve as food for the livestock. Furthermore, the waste of the animals is then collected and converted into biogas, which will be used for two key purposes: to generate renewable energy and to provide heat for a greenhouse, where vegetables will be grown. Moreover, the waste from the livestock will also serve as natural fertilizer for the crops, thus closing the loop.

Figure 2 presents an overview of the proposed farm concept, illustrating the main components and their purposes, as well as the outputs, that generate additional income.

III. DATA PRESENTATION AND DISCUSSION

A. Renewable energy potential of the model

Using floating photovoltaic panels (FPV), it is possible to harness solar energy in a slightly more efficient way, since the water surface generates a cooling effect, therefore reducing the operating temperature of the panel. Another benefit of this system is the reduction of the water evaporation rate, contributing to the conservation of a natural resource [2]. The notable size of the irrigation lake, circa 566 meters in length, 100 meters in width and an average depth of 8 meters, makes it a good candidate for harvesting solar energy. Additionally, the lake introduces the possibility of fish farming, which would not only increase biodiversity within the closed-loop system but could also transform the farm into a recreational area for tourists and fishing enthusiasts, providing an additional source of income and increasing the farm's social and entrepreneurial value.

Considering a 2,15 m^2 solar radiation absorption area, the irrigation lake could accommodate over 26.000 photovoltaic panels. This equates to an installed power of almost 12 MW, considering a nominal power per panel of 445 W. Using PVGIS to simulate the annual production of the FPV field, a maximum of about 15 GWh of energy could be obtained per year [3].

For the considered farmland of approximately 500 hectares, 14 fixed point irrigation systems have been considered, with the following technical particularities:

-Arm length: 300 meters [4];

-Irrigation rate: 36 ha in 12,6 hours [4];

-Water flow: 850 m^3/h;

-Energy consumption: 46 kW/h.

The irrigation system has been proposed as such due to the limited amount of sun light, so that the system`s operation can be powered by the energy generated from the photovoltaic panels. Approximate calculations have shown that for one irrigation event, 8,15 MWh of energy is needed. The results from the solar energy production simulation state that circa 64 MWh of energy can be produced by the FPV on an average day in July, as shown in Figure 3. The big overproduction rate of energy will be assessed, and the number of installed panels will be adjusted in accordance with the cost-benefit analysis.

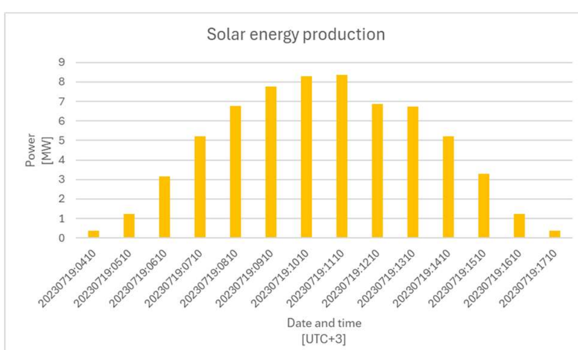

Figure 3. Solar energy production of the FPV field on an average day in July

By having the possibility to irrigate in a sustainable and economically feasible way, it is possible to increase the overall crop and biomass yield of the agricultural land [5]. This allows the farmer to value the secondary product of the harvest, the straw, as biofuel in two ways: directly combusting it to generate heat, and to use fermenting or anaerobic digestion to turn it into biogas or bioethanol [6]. A second crop, such as ryegrass, maize silage or sorghum, can be grown on the same parcel of land after the primary cereal crops have been harvested. These quickly growing species are ideal for post-harvest times and can be used livestock feed as well as biomass inputs for biogas production, increasing land productivity while supporting the circular economy of the farm [7,8].

The biofuels obtained from the harvesting process can be used as an energy source for keeping a greenhouse functioning during the winter, allowing the farmer to maintain production in the cold season and to also obtain a head start on the seasonal vegetable merchandising.

Table 1 presents the main components of the proposed closed-loop, sustainable farm system, highlighting the necessary inputs for establishing each component, the final outputs generated, and how they function within the farm ecosystem. Additionally, the table also highlights the ways in which these components support local employment opportunities by creating varied workspaces that are open to people with any level of educational background. In the end, the system's outputs support the farm's long-term sustainability and financial viability.

Table I

Functional Overview of the proposed Closed-loop Sustainable Farm

Component	**Input**	**Purpose**	**Output / Incoming Funds**
Floating Photovoltaic Panels	-Solar energy	Converts solar energy into electricity for powering the fixed-point irrigation systems	-Renewable electricity for farm operations -Surplus energy delivered into the national grid -Water evaporation reduction
Irrigation Lake	-Rainwater -Ground-water	Acts as a water reservoir and as a base for the photovoltaic panels	-Water source for irrigation and livestock -Fish farm -Recreational area for tourists and fish enthusiasts
Cereal Cultivation (Primary and Secondary Crop)	-Irrigation water -Sunlight -Seeds -Soil -Organic fertilizer from animal waste	Production of food, animal feed (realized all year round due to the secondary harvest), bioenergy after processing and economical gain	-Cereal grains, serving as animal feed and incoming funds -Straw bales valued as biofuel
Livestock Farming	-Cereal feed -Water -Shelter	Raising animals for dairy and meat production, fed from the farm`s own production	-Dairy and meat -Waste used as fertilizer for crops or converted into biogas for greenhouse heating
Biogas Plant or Biomass thermal power plant	-Livestock waste -Straw bales	Anaerobic digestion of waste materials and energy valorisation by direct combustion of bales	-Biogas for heating the greenhouse, animal shelters and farmer’s house or for the animal feed manufacturing unit
Greenhouse (Vegetables)	-Heat from the Biogas Plant or biomass	Controlled-environment agriculture with year-round vegetable production	-Organic vegetables that generate financial income

Component	Input	Purpose	Output / Incoming Funds
	thermal power plant -Water -Light		
Social Component	-Local population	Providing well-paid jobs year-round to the local population to reduce depopulation	A motivated and economically developed local community based on sustainable principles

B. Cost-Benefit Analysis

The first stage of the cost - benefit analysis focuses on evaluating the current farm scenario, where the farmer depends on the electricity provider for irrigation. Setting a baseline for the farm's operating costs and identifying the main economic challenges, particularly the high electricity costs related to irrigations, are the goals of this first step. By first analysing this scenario, we can better understand the current inefficiencies and evaluate how the use of photovoltaic panels could have a visible and quantifiable effect on reducing the energy costs. This initial analysis aims to establish the foundation of the future evaluation consisting in the more complex full closed-loop system, providing valuable information regarding the energy needs of the farm.

Thus, for the present paper, two scenarios have been taken into consideration. The first one, with no investment, presented in table 2, shows the approximate price that the farmer must pay for the irrigation of the fields. The price includes the water pumping costs and the system operation costs. In the second scenario, illustrated in table 3, a floating photovoltaic system was proposed, with a total of 1034 panels, resulting an installed power of 460 kW. The monthly energy production was considered, so that the system would be capable to produce sufficient energy to cover the pumping and irrigation system energy demands.

Table II

Scenario I: No investment

Component	Quantity [MWh]	Cost/ MWh [€]	Total Cost [€]
Annual electricity cost for irrigation	244.5	200	48 900

Table III

Scenario II: Floating Photovoltaic Panels

Component	Quantity [MWh]	Unit	Cost/ Unit [€]	Total Cost [€]
Floating Photovoltaic Panel (P=445 W)	1034	Pcs.	150	155 100
Simple Invertor (P=115 kW)	4	Pcs.	5000	20 000
Installation cost	1	Est.	35 020	35 020

By considering the initial cost of investment, energy production, and the possibility of selling the excess energy to the grid (a conservative 0,1 euros/kWh were considered, as shown in table 4), the payback period will amount to about 3 to 4 years, depending on economic and environmental factors.

Table IV

Energy Production Simulation

Component	Quantity [MWh]	Cost/ MWh [€]	Total Income [€]
Simulated annual energy production with FPV	577.4	0	0
Annual electricity cost for irrigation covered by the FPV field	244.5	0	0
Estimated annual energy surplus sale	332.9	100	33 290

Taking into consideration the technical and economic aspects of the proposed farm model, the size of the floating photovoltaic panel system ought to be corelated with the real farming energy demands (irrigation, powering facilities, equipment, lighting, etc.). Therefore, the installed power in Scenario 2 can be augmented if the farm owner has equipment with high energy consumption.

CONCLUSIONS

The paper aims to show that the closed-loop farming model embodies a holistic and systems-based approach to a sustainable agriculture. By integrating various components, such as crop cultivation, irrigations systems, livestock farming and biofuel management into a self-sustaining cycle, closed-loop systems significantly reduce external inputs and environmental externalities. The model not only enhances efficient resource management but also promotes long-term agricultural resilience. Moreover, the implementation of such systems can generate positive social impacts by creating employment opportunities within nearby communities, fostering local economic development and strengthening rural livelihoods.

Next step of the research will focus on continuing the simulation by including the livestock farm, crop production, greenhouse, and the biogas plant to create a more complete and realistic model of the system. Moreover, future research could focus on improving the current developed closed-loop system by combining more precise resource management technologies, such as automatic irrigation, compost monitoring, and renewable energy integration, in order to improve both environmental and economic performance. Expanding the model to other Romanian regions might help in determining its adaptability to varied soils, climates, and local people, as well as investigating ways to improve local employment and educational opportunities. Long-term studies on the farm's productivity, waste reduction, and financial sustainability would also provide useful insights for expanding the Mioritic Loop concept and promoting it as a model for sustainable agriculture in Romania.

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