TECHNICAL REPORT AGRIVOLTAICS FOR NOAH'S ARK

AN ECOLOGICAL PERSPECTIVE OF LANDSCAPE PLANNING.

The energy transition is one of the future challenges we face and offers us the opportunity to significantly improve the efficiency of processes and actions to transform the landscape towards a more sustainable model. The urgent challenges we face are:

1. Reduction of biodiversity loss.
2. Mitigation of the negative impact of human activity on landscape.

To address these issues, it's necessary:

A. Design with a holistic approach, performing a rigorous diagnosis of landscape structure and dynamics; this will help to develop much more effective strategies to improve landscape resilience.

B. Consider the supporting, provisioning, regulating and cultural ecosystem services (Ref. CICES, Common International Classification of Ecosystem Services): these provide a solid orientation when defining and planning actions and design criteria, and allow quantitative evidence of how each contributes to improving people and environment well-being.

These aspects have served as the basis for the configuration of the proposal based on the concept of green infrastructure. Green infrastructure can be broadly defined as a strategically planned network of natural and semi-natural areas which, with other environmental elements, is designed and managed to:

1. Provide a wide range of ecosystem services

2. Enhance the biodiversity of both rural and urban settlements.

According to these goals, in the project area – integral part of the active and dynamic ecological infrastructure - natural and productive spaces will act as a multifunctional resource capable of providing ecological benefits, environmental, social, economic, etc. services. Increased efficiency will improve not only the quality of a such singular landscape as the HUB is, but also the local community well-being: regarding mobility for instance, the aim will be to create structured connections between the urbanization and the HUB; the green areas will create spaces that, on one hand, will ensure people's comfort, and on the other, will enhance ecological connectivity. Similarly, within the agricultural space, functional and management criteria will be established to ensure agricultural benefits, promoting local culture, etc.

GREEN INFRASTRUCTURE GOALS

- Improvement environmental services. Natural resources optimization, use and management.
- Design of a more comfortable and beautiful landscape.
- Mitigation of climate change effects
- Enhancement of biodiversity
- Production of socio-cultural and economic benefits for the local community.

DESIGNING INNOVATIVE AGRIVOLTAIC SYSTEM

ENERGY PRODUCTION

The design of the agrivoltaic landscape is relatively complex, as it's necessary to combine solar infrastructure with food crops for optimizing land use. Its design and evaluation must conform to the requirements set in the design phase, to meet the desired performance and quality objectives. [1]. Experimental results show that rice yield is positively related to solar radiation, especially during the reproductive and ripening stages [2]; on the other hand, shading significantly affects the main components of the rice crop - panicle number, SPAD value and grain quality [3] - reducing its yield. In addition to the design parameters (to ensure the maximum yield of agricultural and energy production), other factors need to be considered, such as: the good performance of agricultural tasks, ecological functionality, maintenance and management costs of the PV system, safety, and visual integration. In relation to agricultural tasks, the proposal foresees that these can be carried out with the same machinery used in the adjacent fields.

The technical solution proposes:

- 550 W monocrystalline photovoltaic modules, high energy efficiency up to 21.3%, PERC 10BB half-cell technology, maximum annual degradation of 0.55% after 25 years.
- Three-phase inverters of 20 kW, with a maximum DC voltage range of 200-1,000 V, without transformer, with a standard interface for easy communication via WLAN or Ethernet. IP-66 degree of protection, ambient temperature range of -40ºC to +65ºC and admissible air humidity of 0-100%.
- Galvanized steel structure, anchored directly to the ground and designed to resist the self-weight of the modules and wind and snow overloads according to the existing standard.

The arrangement of the modules, south facing, with an inclination angle of 33° will ensure an energy efficiency of the system of 99.71%.

Photovoltaic modules orientation

The east-west orientation of the structure (9x9 meters) allows the panels to be arranged in a north-south direction for the maximum energy production; the distance between rows of modules and between modules allows the maximum advantage of solar radiation, shade's homogeneity and optimization of agricultural tasks.

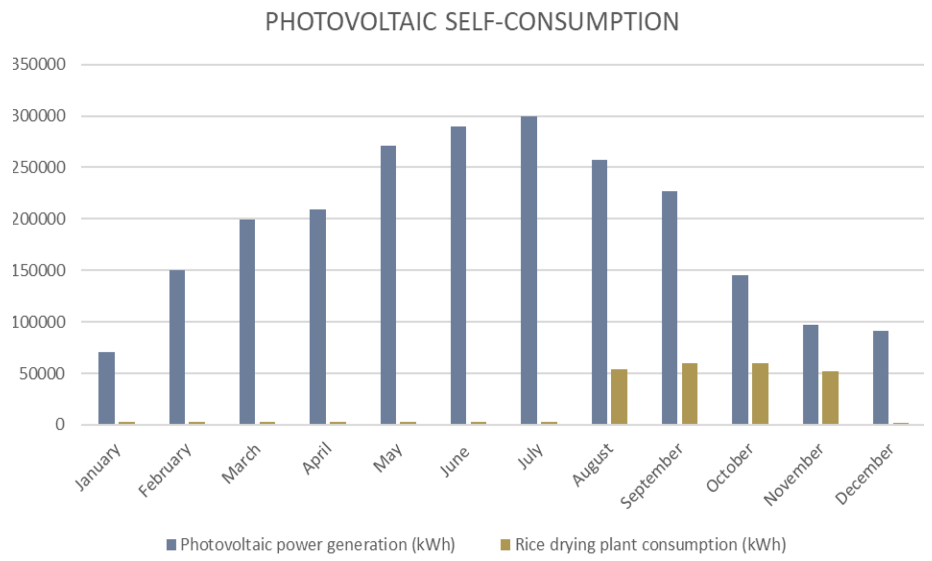
Panels arrangement. Fixed solution. This solution is proposed because rice is a crop that does not benefit from shading, as mentioned above. Therefore, monitored shade is not required. The option of a fixed structure simplifies and reduces both installation costs, (during purchase and assembly of the equipment) as well as maintenance costs (needs less maintenance staff and monitoring).

<u>Tilt angle of the solar panels</u>.

The tilt angle of the fixed solar module directly affects the module's performance, energy production, the shade cast on the crop and the level of crop productivity. To maximize the latter parameter, a tilt angle of 33° is proposed (have been taken as reference the results of the research study by Thum Chun Hau, [4]. adapted to the geographical coordinates of the area, it is therefore equivalent to the 25° angle of the study.

This angle turns out to be the optimum inclination to obtain the maximum benefit in terms of productivity and a slightly higher monetary return compared to others studied (14°, 42°, 60°). This conditioning factor will be also relevant in the critical period of rice growth (August), which starts from the formation of the panicle until the medium drought stages.

For better energy efficiency, part of the energy generated can be used for self-consumption in the existing rice drying plant (next to the project area). Months of greatest activity of the drying plant coincide with months of high energy generation: August September October. Considering that the drying plant has an estimated annual consumption of 248,811.52 kWh, and the solar plant generates 2,309,281.54 kWh annually; Part of the energy generated during solar hours will be self-consumed by the drying plant. The rest of the energy generated will be injected into the electric power distribution.



AGRICULTURAL PRODUCTION

The plot is integrated into an organic farming system, so it is proposed to incorporate the practice of green manure cultivation into the crop rotation. Fig.1 shows the crop rotation sequence: green manure-rice-soybean-green manure-rice. This will reduce fertiliser input, increase organic matter content, and reduce pressure from adventitious flora (Filizadeh, Y. et al., 2007).

Once the installation of the photovoltaic infrastructure has been completed, the rotation will start with the cultivation of green manure, as the plot will be compromised by possible soil movements and compaction by the machinery necessary to carry out the photovoltaic construction. Green manure in rotation makes sense to improve soil conditions.

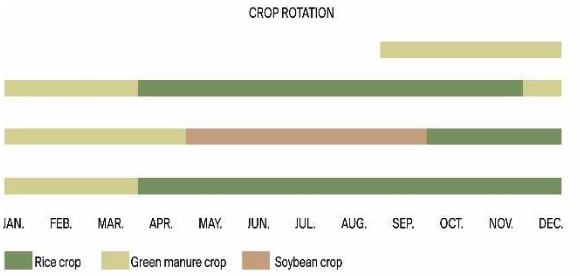
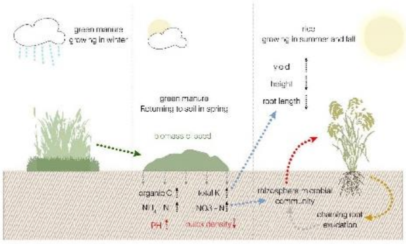


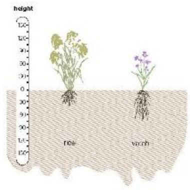
Figure 1. Sequence of crops rotation

A mixture of five annual clovers or similar will be chosen because of its high speed of implementation, which will limit the development of weeds. This mixture will provide nitrogen for the following crop and will incorporate organic matter into the soil, increasing its fertility. The clover is mowed, the clippings are evenly distributed on the field to prepare the land for the next rice crop. Then, after preparing the soil, the rice (Oryza sativa) is sown. For the management of the rice, direct dry sowing is proposed, as it saves seed. This will also save water: from sowing to the first flooding can take between 20-30 days depending on the sowing dates and the variety. Direct dry sowing can be a good tool for the control of the rice weevil (Lissorhoptrus oryzophilus), as it delays the flooding of the paddy reducing the damage caused by the larvae of this pest (Villegas, J. M. et al., 2021). Post-emergence mechanical weed control will also be carried out using a precision harrow with flexible tines or a rotary hoe, and it is important to do this at the optimum time for effective weed suppression (Neeson, R., 2005). To complement the rice field fertilization strategy, the foundation plant management biofertilizer will be applied before planting. During the winter break and weather permitting, a green manure crop, a mixture of rye (Secale cereale) and vetch (Vicia sativa), will be sown. This mixture is characterized by fixing nitrogen and improving the soil structure due to its deep roots; this will provide better soil drainage.

The management will be the same as for the previous green manure: at the optimum stage it will be mowed and incorporated into the soil again. Two to five blind cultivations are made before inter-row cultivation commences. To obtain satisfactory yields, irrigation should be carried out only when necessary. Once the soya beans have been harvested, the green manure crop is cultivated, and it is advisable on this occasion to mix two short-cycle species: chervil (Vicia ervilia) and mustard (Alba Synapse). Vervil is a legume that will help fix nitrogen and provide fertility. Mustard is a fast-growing crucifer, very good at suppressing weeds (Rosenfeld, A. and Rayns, F., 2018) and high in glucosinolates; under the right conditions it can deter and even kill pests and diseases. Management will be the same as for previous green manure crops. The agrivoltaic system is still a new concept, which is why it is proposed to monitor different parameters at different points in the cultivation area to value the temperature and humidity (air and soil), development and yield of the crop. To understand the impact of photovoltaic shading on different crops.

Therefore, it will be necessary to install different sensors to monitor them and to be able to draw conclusions about the effect of shade on crops, especially during hot and dry summers when it has been seen that the AGRIVOLTAIC system can have a beneficial impact on the performance of these (Weselek, A. *et al.*, 2021).





Crop Rotation

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[2] *Evans, L.T.; De Datta, S.K. The relation between irradiance and grain yield of irrigated rice in the tropics, as influenced by cultivar, nitrogen fertilizer application and month of planting. Field Crop. Res. 1979, 2, 1–17.* Available online at: *[https://www.sciencedirect.com/science/article/abs/pii/0378429079900029?via%3Dihub]*

[3] Ruth Anne Gonocruz, Ren Nakamura, Kota Yoshino, Masaru Homma, Tetsuya Doi, Yoshikuni Yoshida and Akira Tani. Analysis of the Rice Yield under an Agrivoltaic System: A Case Study in Japan. 2021. Environments-MDPI. Available online at: *[https://www.mdpi.com/2076-3298/8/7/65/htm]*

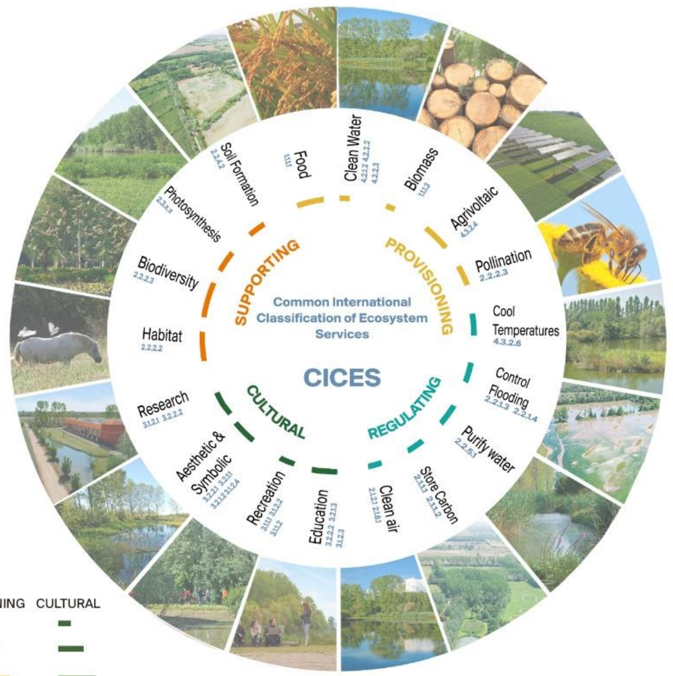
[4] Thum Chun Hau, Kensuke Okada. Simulation Approach to Estimate Rice Yield and Energy Generation under Agrivoltaic System. Master – Thesis 2019. Available online at: *[https://ipads.a.u-tokyo.ac.jp/wp/wp-content/uploads/Master-Thesis-Thum-Chun-Hau.pdf]*

ARISING LANDSCAPES

In the study area, the urban landscape, the agricultural pattern, the natural environment, etc., represent a valuable mosaic that can provide a higher quality environment and greater social and economic possibilities. **The proposal is based on the concept of green infrastructure**, a strategically planned network of natural and semi-natural areas which, with other environmental elements, is designed and managed to:**1. Provide a wide range of ecosystem services 2. Enhance the biodiversity of both rural and urban settlements.** This will also: a. Promote a better quality of life and well-being in the landscape where people live and work - b. Enhance biodiversity, by strengthening natural areas connection, thereby increasing wildlife mobility in the wider landscape - c. Counteract the effects of climate change, mitigating the impact of flooding, storing carbon, etc- d. Promote a more efficient and integrated approach to landscape development. According to these premises, the actions foreseen in the project area, which can be consistently extended to the rest of the territory, will contribute to improve nature's capacity to provide the local community with multiple and valuable ecosystem services. (See panel 1)

ccording to these goals, in the project area natural and productive spaces will act as a multifunctional resource capable of providing ecological benefits, environmental, social, economic, etc. services.

ECOSYSTEM BIODIVERSITY PERFORMANCE. The production of organic goods derived from the NEORUALHUB activities, together with the enhancement of ecosystem diversity, has already increased some of the Provisioning Services of the pre-existing ecosystems, adding and/or enhancing Supporting and Regulating Services. According to the goal's proposal, these, but especially the Cultural Services, will be increased thanks to the regulation and implementation of new uses in the project area.



Quantitative description of the Ecosystem Services (CICES) provided

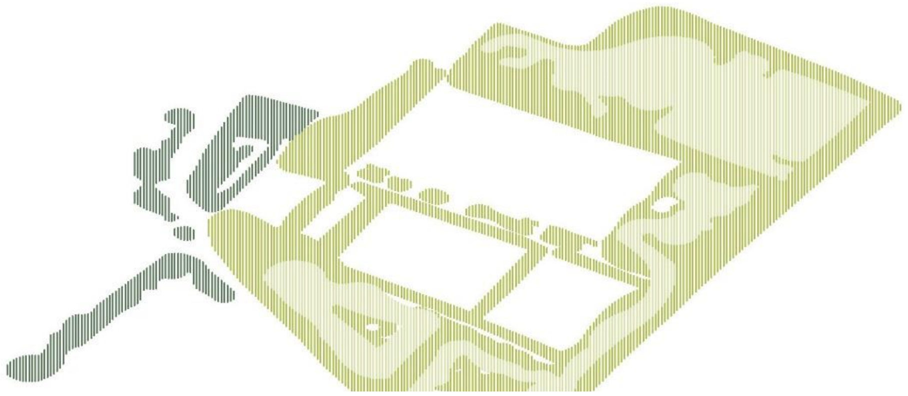
Agrivoltaic proposal

Modulation and regulation of activitie's areas

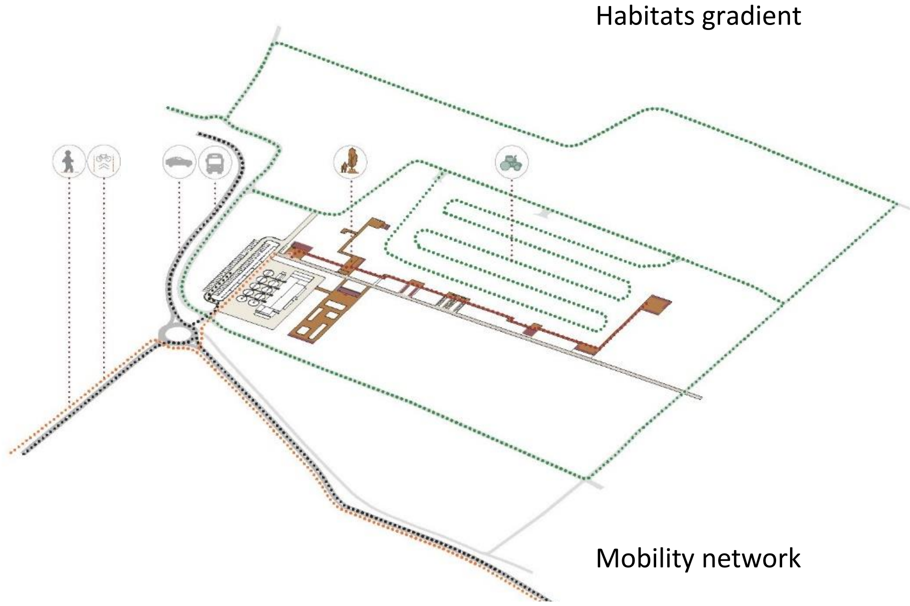
ECO-ENVIRONMENTAL OBJECTIVES. The strategic approach applied to the area is based on the simultaneous consideration of three relevant aspects (Green Infrastructure, Nature-Based Solutions (NBS), Ecosystem Services).

The innovative offer of NEORURALEHUB, which has been consolidated over time, will be displayed in a new space that will invite different users (private, academic, scientific entities, etc.) to interact and discover the multiple relationships with the natural and cultural world of the place. In a clear commitment to a quality landscape, appropriate to human requirements, the project establishes a manifesto in 4 points:

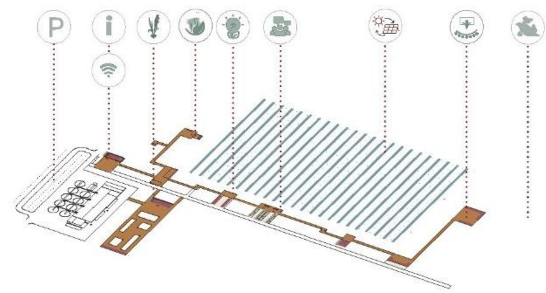
1. To generate a productive landscape - 2. To improve the dynamics of the place - 3. To enhance and reinterpret the existing landscape - 4. Consider landscape as a living system



Habitats gradient



Mobility network



Services and activities

The proposal is articulated by keeping energy and agricultural production at the centre of the plot; then are set up two paths (north-south direction):

The first (west) welcomes various activities' and foster the greatest flow of people; according to a didactic-scientific, entertainment programme; along the path, the design of a wet landscape helps to recreate different "horizons". Expression of technological innovation, new trends in efficiency and sustainable design, these areas are designed using the so-called Nature Based Solutions (use of draining and light-coloured paving, planting of native species, etc.).

The second, used just for agricultural production and maintenance (thus less frequented), will help to preserve the natural dynamics of the wetland area as much as possible.

Relevant disturbances in the north-western sector, as well as in the central part of the northern boundary, are balanced out by the allocation of part of the agricultural field - in the southern area - to natural space; this, in continuity with the area to the east, will enhance the natural dynamics in a west-west direction.

The perimeter natural areas, organised in organic forms, are set balancing the geometric shapes of the existing agricultural fields and tree alignments.

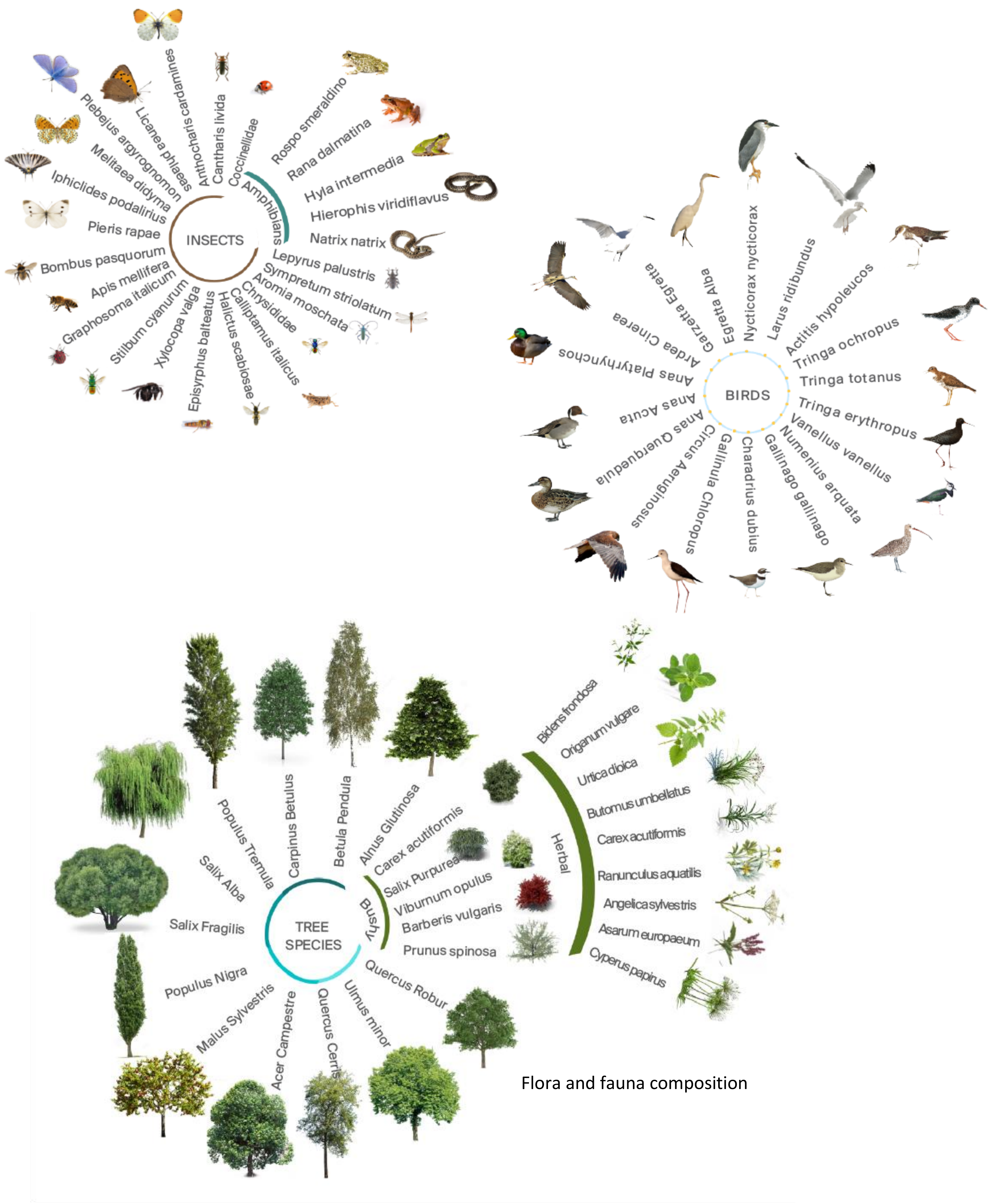
BIODIVERSITY: MAIN SPECIES OF FLORA AND FAUNA INVOLVED. In the study area there are 14 dominant species of flora: 14 herbaceous, 17 shrub and 15 tree species. In terms of flora species richness, 874 taxa have been described. In terms of fauna in the area, at least 20 insect species and 30 vertebrate species have been identified as dominant species, including 20 birds.

CONSTITUTION OF BIODIVERSE HABITATS. The idea underlying the proposal is the constitution of gradient habitats: forest zone - semi-humid - humid (with the corresponding areas of structure and vertical cover, whether herbaceous, shrubby or arboreal). These three levels of ecological complexity, considering their progressive maturation and correct functionality, will be reinforced over time thanks to the interactions that will be established in the proposed ecosystems.

SEMI-HUMID AND HUMID ZONES. With a strip of biodiverse vegetation (panel 2), the enjoyment of the naturalised area will be encouraged here without providing internal routes into the natural space to maintain its biodiversity unaltered. This area will function as a "corridor", as it will be contained on both sides by crops, except in the vicinity of the open spaces at the ends of the agricultural area (where relaxation, entertainment and observation points are planned). The natural area in the south, will act as a refuge for the wild fauna.

FORESTRY ZONE. To ensure maximum biodiversity, at the entrance in the north while preserving the existing canopy is reinforced with other species (Quercus robur, Ulmus minor, etc.). As far as forestry is concerned, its management should be as sustainable as possible, maintaining the emerging properties of forest habitats and their corresponding ecosystem services. As a general forestry management strategy, it is proposed to carry out selection thinning in a 25-35 yearly rotation with removal of stands to reduce the basal area by a certain percentage, but without seriously damaging the crown, the buffer effect, the impact of rainfall, the minimisation of soil loss through erosion. All this without compromising biodiversity or the ecological quality of the forest (trophic pyramid, microhabitats, maintenance of CO2 absorption and the natural water cycle, nutrient cycle, ecosystem stability). Combined with this temporary intervention, the extraction of the necro mass generated every 2-3 years can be considered so that it can be used for biomass energy production.

As the project area, due to its size and geometry, is representative of the agricultural pattern of the area, a coherent development model can be extended to future actions in the surrounding area.



Flora and fauna composition

ECONOMIC EVALUATION OF THE AGRIVOLTAIC SYSTEM

APV System

Technical Data	
Total module area	8 062.08 m²
Total module number	3 120
Total inverter number	78
Annual total energy	2 309 281.54 kWh
Total power	1 716.000 kW
Power phase L1	572.000 kW
Power phase L2	572.000 kW
Power phase L3	572.000 kW
Power per kW	1 345.74 kWh/kW
Useful storage capacity	-
BOS	87.42 %
Economic data - Construction	
Cost of works: modules, inverters, electrical material and monitoring (415.00 € / kW)	712.140,00 €
Technical expenses (design and installation, 25.00% of cost of works)	178.035,00 €
Other expenses (Structure)	250.000,00 €
Total cost €	**1.140.175,00 €**
Economic data - Operation and Maintenance costs	
Periodical	
Anual Maintenance (5,83 €/kWp)	10.000,00 €
Anual Insurance (11,66 €/kWp)	20.000,00 €
Annual amount	30.000,00 €
One-off costs - Year num. 10 (estimate)	
Extraordinary maintenance (2,91€/kW)	5.000,00 €
Inverter replacement (2,91 €/kW)	5.000,00 €
Annual amount	1.000,00 €
Annual amount O&M	**31.000,00 €**
ESTIMATE ECONOMICAL BALANCE	
Annual energy generation	2 309 281,54 kWh
Annual rice drying plant comsuption	248 811,52 kWh
Annual Self-comsuption energy	248 811,52 kWh
Annual surplus energy	2 060 470,02 kWh
Self-comsuption Average Tariff	0,2500 €/kWk
Energy sales tariff Electric market	0,090 €/kWh
Taxes (fixed IRPEF 23.00 % + IRAP 3.90 %)	
Income	
Self-comsuption economy	62.202,88 €

Energy sales Electric market	207.835,34 €
Outcome	270.038,22 €
Taxes	72.640,28 €
Operation and Maintenance Costs	31.000,00 €
Total balance firts year	166.397,94 €

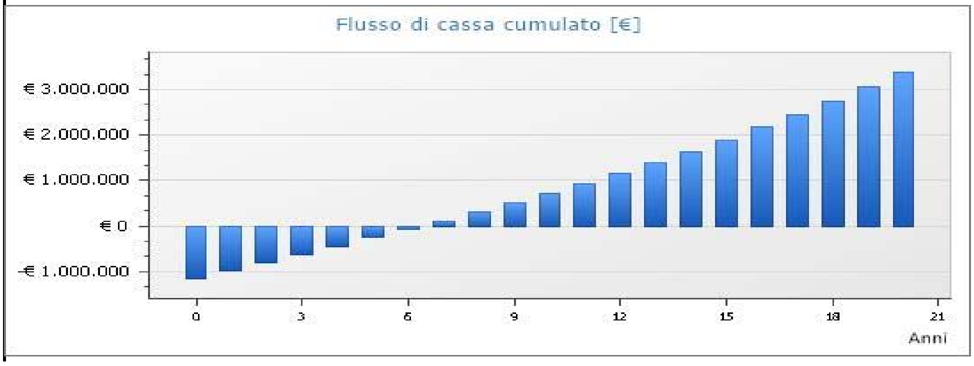
Payback period

For the purposes of the economic analysis, considered:

Aliquota IRPEF fissa	23.00 %
Aliquota IRAP fissa	3.90 %
Tasso di inflazione annua dei costi	2.00 %
Tasso di inflazione annua delle tariffe energetiche	6.00 %
Tasso di attualizzazione	4.00 %
Aumento annuo dei consumi di energia	2.00 %
Perdita annua di efficienza dell'impianto	0.50 %

The number of years required to offset the initial investment through positive annual flows is 7.

The Internal Rate of Return (TIR) he maximum cost of financial means that should be assumed, estimating a useful life of the plant of 20 years, is 16,17%.



AGRICULTURAL SYSTEM

Crops land area	4,86 ha
Average rice yield/production	6 tn/ha
Average estimated rice yield in AVS* (considering 20% yield loss)	4,8 tn/ha
*Homma et al. (2016) found a 20% reduction in solar radiation led to a	
Estimated total rice production in AVS area	**23,3 tn**
Production costs	1705 €/ha

Income	
Payment Common Agricultural Policy (CAP) 2015-2020 programming period (basic title + greening + coupled aid)	692 €/ha
Carnaroli rice price (Vercelli-IT) Juny 2022	986 €/tn

ECONOMICAL ANUAL BALANCE

Income CAP	3.360,56 €
Income rice sale	22.983,90 €
Estimated total rice production costs	-8.279,99 €
	18.064,47 €

ECONOMIC SUMMARY	
Estimated Annual Benefits PHOTOVOLTAIC SYSTEM	166.397,94 €
Estimated Annual Benefits AGRICULTURAL SYSTEM	18.064,47 €
	184.462,41 €

E C O N O M I C   A S S E S S M E N T

PROJECT AREA	SURFACE (m2)	COST
1.1 Energy field	48.563	1.140.175 €
1.2 Agricultural field	48.563	8.280 €
2. Mobility and activity areas (cultural, scientific,etc.)	158	0 €
3. Pavillions and service facilities	401	401.000 €
4. Semi-humid areas	0	0 €
5. Wetland areas	0	0 €
GLOBAL AMOUNT (taxes and VAT included)	49.122	**1.549.455 €**

OUT OF THE PROJECT SCOPE		TOTAL AMOUNT
6. Main entrance	7.487	0 €
7. Pavillion exibition area	256	256.000 €
8.Open space exibition area	0	0 €
9. Pavillion entrance	0	0 €
9. Semi-humid areas	0	0 €
10. Wetland areas	0	0 €
GLOBAL AMOUNT (taxes and VAT included)	7.743	**256.000 €**