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N O D e 4 R E S A

new origami design for renewable energy smart agriculture

Executive Summary

Given the growing pressures of **climate change** on vineyards and **competition for the soil** of the last decades, the project aims to protect vineyards from harmful weather phenomena, while contemporarily harvesting energy through photovoltaic panels.

Global warming is leading to an intensification in rainfall, droughts, hailstorms, windstorms and spring frosts, which can highly damage vineyards[1], therefore protective systems are needed, such as the commonly used anti-hail nets. In addition, proper land use is an increasingly difficult issue, because of the conflict between sustainable energy production through photovoltaics panels and the need to maintain high agricultural productivity, which is leading to the development of the Agri-Voltaic field, to create a synergy between the two kinds of land use[2].

The NODe4RESA (New Origami Design for Renewable Energy & Smart Agriculture) solution considers both these needs, and, to do so, is based on the implementation of **deployable coverage** integrated with an **Agri-Voltaic system**, exploiting an origami-based design.

The origami-based cover is realized through anti-hail nets and a light aluminum support, with an array of mountain and valley folds, to enhance fast and efficient deployment and to reduce the shadow on the crops in the closed configuration, while a solar tracking system is implemented to maximize energy production. Materials and techniques are defined to reduce the environmental impact, still guaranteeing high durability in the agricultural environment.

The expected outcome is a light modular system, which complies with the protection requirements and the need to reduce the carbon emissions in the energy production field.
In addition, it can easily be customized, according to the requirements of a specific region.

The economic feasibility is analyzed, thus, a first-generation business model is provided, to collocate the solution on the Agri-Voltaic market while reducing vineyards owners' effort.

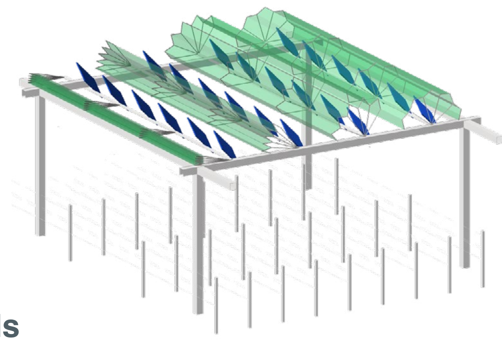


Fig 01 Overview of the structural module in the vineyard

Key Words
•Agri-Voltaic
•Smart agriculture
•Deployable structures
•Vineyard's protection
•Climate Change

Project description and Team description

NODe4RESA project aims at designing a protection system for vineyards, coupled with power production by integrating PV panels on a deployable origami structure. The integration consists in installing the modules on the structure, in order to reach the double goal of protection and production.

The chosen location for the scenario is the Italian region of Puglia, thanks to a direct contact with the owners of a vineyard there.

The team conceptualized different solutions based on the vineyards requirements, to achive this double goal. Consequently, a definitive solution has been identified and a more detailed analysis of its specification has been developed.

The project evolved through the following steps.

•At first, students have conducted an investigation on the **vineyards main risks and vulnerabilities**, to understand the ideal environmental conditions for the crops, with a focus on the impact of climate change and the related harmful weather phenomena. The initial phase also included the analysis of the **stakeholders** and the **state of the art** concerning the fiels of Agri-Voltaics, origami and deployable structures, and the currently used protective systems n agricultural field.

•Once the project requirements were defined, the team has produced and evaluated a wide range of **possible solutions**, discussing their benefits and drawbacks. Some employed the vineyard existing support structure and its geometry to support the Agri-Voltaic system. Others were based on fixed or movable overhead grid canopy, with different origami-based covers.

•It was decided to focus on the concept of an **overhead fixed grid** canopy with a protective system made of anti-hail nets following the mountain and valley origami fold.

•After the definition of the final concept, the team focused on the analysis of the **design specifications**, in terms of the geometry of the origami-based cover, the materials and the structural components. An indepth analysis has been done on the photovoltaic panels integration with the solar tracking system and the evaluation of the shading effect on the crops.

•In the last phase, the team studied the economical feasibility of the project and evaluated its environmental sustainability. In addition, the NODe4RESA team joined the Switch2Product programme of Politecnico di Milano, to get the technological validation and entrepreneurial acceleration of their solution.

The NODe4RESA team is composed of seven members with different backgrounds, two architects, a designer and four engineers. Though, the team had no skills in the agricultural practices and requirements, these themes were deeply studied in the first phase of the project.

The presence of the architects and the designer helped in the developing of the possible solutions, with graphical representations and small paper prototypes of the origami folds for the design of the cover system. The definition of the definitive solution specifications was allowed by the presence of an Energy engineer, for the design of the PV panels solar tracking system and the analysis of the shading on the crops.

The definition of the structural components was done by the two Civil engineers, and the Material engineer studied the most effective materials, and carried out the analysis of the environmental sustainability. The presence of an architect with skills in the field of three-dimensional printing was also crucial for the realization of the prototypes.

Goal

The project fits in the field of innovative solutions for the **integration of photovoltaic energy production** on the cultivated land and in the development of n**ew protective deployable structures** based on the origami techniques.

Both these research fields are deeply analyzed, and it has addressed the project's objectives to the definition of a suitable origami structure integrated with the photovoltaic.

Considering the research outputs, the project goals are:

•Grape protection against overheating period that could destroy the vineyards;
•Helping farmers to prevent the lack of water due to high temperature and evaporation;
•Grape protection from the hailstorms and during the spring frost.

Therefore, the main objective regards the real **time adaptability** that is linked to the kinetic **electric mechanism** embedded with a minimum level of automations in the structures. In order to adapt to various vineyards dimensions, the structure must be modular, and its assembly must be easy. The solution must also be compatible with the photovoltaic panels and their solar tracking system to boost efficiency.

Finally, another important goal is related to the reduction of the impact of the solution on the **landscape**, which is inevitably is altered by the presence of protection systems.

In achieving these goals, great attention is given to the **economic and environmental feasibility** of the project.

Understanding the problem

According to the last report by the Intergovernmental Panel on Climate Change (IPCC), the global warming phenomenon is bringing to an increase of the average global temperatures of 1.5°C in the next 20 years[3]. Consequently, the IPCC prospects the water cycle intensification, with more intense rainfall followed by more severe droughts, dramatically affecting the agricultural field.

This tendency, moreover, could turn even more serious if the global greenhouse gases (GHGs) emissions are not reduced most rapidly and decisively as possible. Therefore, the introduction of carbon-free technologies is essential, especially in the energy production field, which has the greatest impact on carbon emissions at the global level. One of the most promising technologies in this sense is represented by solar photovoltaic panels systems, even if their installation at a large scale leads to high soil exploitation.

Fig 03.
An Agri-voltaic system

Available from: Agrivoltaics, Fraunhofer Institute for Solar Energy Systems ISE https://www.ise.fraunhofer.de/en/key-topics/integrated-photovoltaics/agrivoltaics.html

Besides, with the world population projected to exceed 10 billion individuals by 2100 according to the UN[4], the use of soil for crop cultivation is becoming a more and more crucial topic, and competition for soil use is arising.

In this framework, it is necessary to think of an Agri-Voltaic system that can also prevent the weather events to severely affect the plantations.

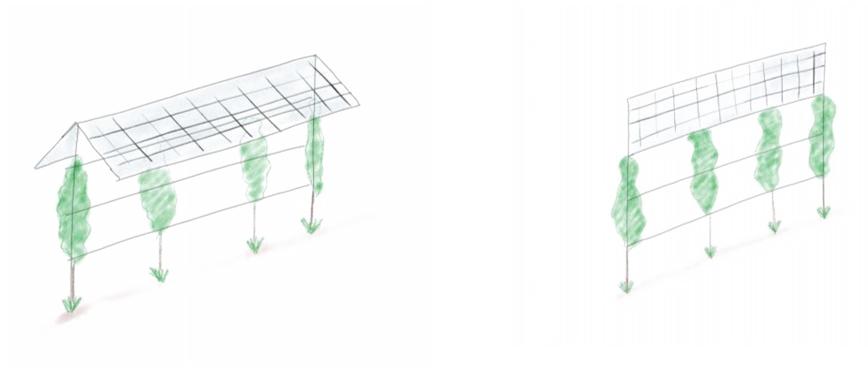
Exploring the opportunities

The identified specifications allowed the team to define five main concepts, each of them tackling the problem with a distinct approach, thus resulting in five novel designs which combine protection and energy harvesting in a different manner. Even though four of them were eventually discarded, their features and mechanisms contributed to the development of the final design of the chosen concept.

The first concept takes advantage of the vineyard support structure and its geometric layout, by the installation of two photovoltaic panels hinged on top of the trellis.

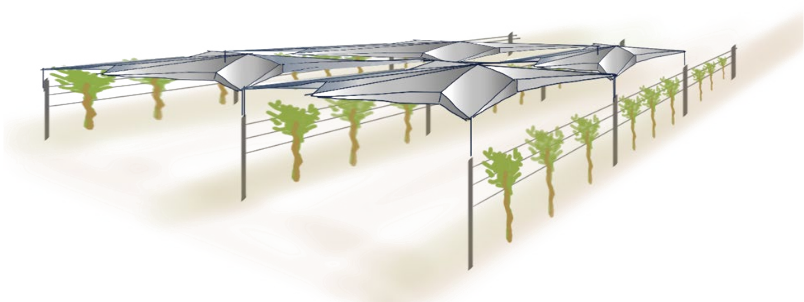
The hinge allows the panels to rotate with a book-like motion, therefore, when a hailstorm or heavy rain is forecasted, it is possible to create a roof-shaped shelter for the plants and protect them from the weather, as depicted in the first sketch of Figure 4. The main problem of this concept is the impossibility to perform mechanical harvesting, due to the footprint of the panels and the risk of damaging them, even in their closed configuration. To tackle this issue, an alternative design was developed. In this case, flexible panels are adopted instead of the traditional ones, allowing to roll them up as represented in the second sketch.

Fig 04.
Sketches of the two configurations of the foldable cover with book-like mechanism.



The second concept is constituted by an assembly of point spatial devices: it is characterized by different individual structures positioned inside the vineyard rows instead of one plant, as it is possible to observe in Figure 05. During sunny weather, these structures recall a closed umbrella, with a reduced spatial footprint. Flexible photovoltaic panels are applied on its surface, allowing energy production. The geometry is inspired by the AHR Sectors of the Al Bahar towers, in Abu Dhabi.

Fig 05.
Sketch of the umbrella system during its opening.



This third concept comprises a movable overhead structure constituted by vertical poles higher than the vineyard (3-4 meters), and horizontal beams connected by foldable anti-hail nets. In particular, the grid becomes movable thanks to the introduction of wheels at the end of the vertical poles. Moreover, being the structure closed for most of the time, the area available for the panels is small, implying a low energy production.

Although the idea of a deployable structure was discarded, the team investigated more in detail the concept of a grid much higher than the vineyard, this time keeping it fixed to the ground. This gave rise to the overhead fixed grid canopy.

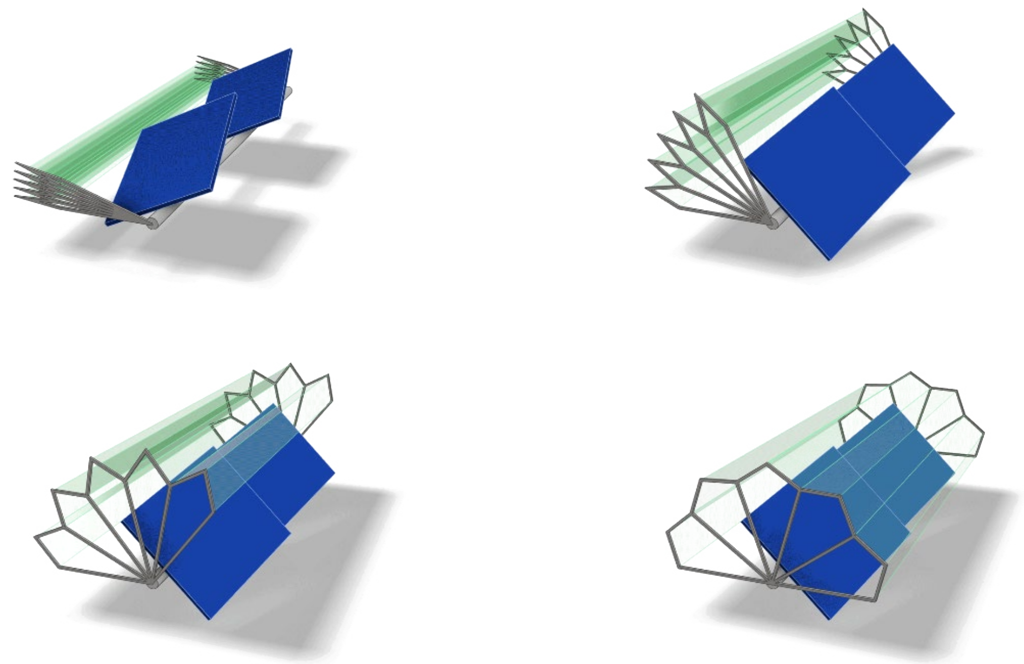
Generating a solution

At the end of the concept formulation's process the most suitable solution was represented by the overhead fixed grid canopy which provides protection due to the presence of a cover system and energy production due to the integration of PV panels.

Our solution for the covering system is meant to be anchored on top of a lightweight structure that hovers on top of the vineyard. Its dimensions are inevitably influenced by the base module of the vineyard. The steel framework touches the ground every eight rows to keep a regular accessibility of the agricultural machine to the vineyard.

The protection cover is able to pass from an open to a closed configuration assuring a less shadow over the crops. It folds in a radial manner, with an array of mountain and valley folds, passing from a planar to a semi-circular configuration that protects at the same time the photovoltaic panels and the crops underneath.

Fig 06.
Conceptual overview of the movement of the covering system



The jointed rigid arms that guide the geometrical development of the movement have a configuration that is similar to scissoring mechanisms. Each rotation joint is respectively connected to the correspondent joints in the neighboring elements by means of steel cables in tension which provide the framework for attachment of the anti-hail nets.

The panels are installed horizontally on an axis oriented from North to South, and rotate during the day following the daily sun route in the sky. Considering the original dimensions of the structure 6 of them can be placed in each row.

The solution disaggregates the covering element and the solar panels, with the clear advantage of using the former to protect the latter. Two different rotating movements have been designed and combined on the same axis: one to allow the opening and closing of the covering structure, and one for the solar tracking of the PV panels.

The double rotation problem has been solved with three concentric shafts: the most internal one has only a structural aim, while the intermediate one determines the rotational movement for opening and closing the nets, and the most external one is responsible for the solar tracking.

Moving to the electrical part of the design, the PV panels, by producing DC current, feed the motor, by means of an inverter which converts the produced current into AC, and contemporarily, when the production exceeds the consumption (most of the daylight time), the surplus electric power is sent to the grid, via a transformer which rises its voltage.

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Fig 07.
Perspective view of the vineyard under the closed system, in case of atmospheric events