Agrivoltaics for open-field agriculture (HyPErFarm)

What is the challenge?

Achieving the EU's medium- and long-term objectives for transitioning away from fossil fuels necessitates the large-scale implementation of renewable energy sources. Photovoltaic (PV) systems are expected to contribute significantly to this endeavour. As reported by Solar Power Europe, there is a need to roll out an impressive 870 GW of solar energy across the EU by 2030 to pave the most cost-effective path toward achieving carbon neutrality by 2050.[15] This aligns with the global shift towards cleaner energy sources to combat climate change.

While rooftop PV systems can serve as an alternative, their scalability is insufficient to meet the massive renewable energy demands for the EU's decarbonization efforts. Consequently, the focus turns to the expansion of ground-mounted PV systems. Nevertheless, this approach can create a conflict between food and energy production, posing potential unintended socio-environmental repercussions.

Agrivoltaics (APV), the synergy of agriculture with solar photovoltaics, emerges as an innovative solution to preserve agricultural land while concurrently generating solar energy. The concept involves integration of solar panels with crop cultivation, ensuring dual land utilization. The HyPerFarm H2020 project conducted a study, identifying prospective APV sites throughout the EU. Astonishingly, the potential capacity for APV systems in Europe is estimated at 51 TW, which could yield approximately 71,500 TWh of electricity annually.[16]

Furthermore, climate change poses an imminent threat to agricultural productivity within the EU, with studies indicating a projected decline in crop yields. In this regard, APV systems can prove to be invaluable. The thoughtful incorporation of solar panels in agricultural fields can shield crops from extreme weather conditions and create microclimates that are conducive to agricultural productivity.

However, the path towards APV maturity is filled with challenges, including optimisation of agricultural yields in tandem with solar energy production, building a robust APV business model, and developing supportive regulatory and policy frameworks for APV systems. Moreover, the EU's Common Agricultural Policy (CAP) and national policies should consider supporting APV systems as a sustainable practice, encouraging adoption by farmers.[17]

APV systems are particularly viable for orchards, vineyards, greenhouses, and arable crops, albeit with varying complexities. For many farmers, investing in agrivoltaics is a leap of faith due to the lack of supporting infrastructures and unfamiliarity with the multifaceted benefits of the technology. Most farmers have yet to embrace the dual role of being an energy producer while farming. Hence, the establishment of demonstration sites, such as those under the HyPErFarm project,[18] is crucial for illustrating APV efficacy. Moreover, the development and deployment of intuitive tools for assessing the performance of agrivoltaic systems are imperative.[19] There is also a need for additional pilot projects to examine the influence of APV on crop behaviour under diverse climatic conditions and to ascertain the optimal balance between shading and electricity generation.

Lastly, even with positive results from pilot projects, farmers must critically assess various aspects such as the positioning of APV systems on their farms, energy management strategies (including consumption, surplus sales, and on-site storage), and the current and anticipated levels of farm electrification. Comprehensive educational programs, financial incentives, and agricultural extension services can facilitate the seamless integration of

[15] SolarPower Europe (2021): EU Market Outlook for Solar Power 2021-2025
[16] Niazi, K.A.K, Victoria,M. (2023). Comparative analysis of PV configurations for agrivoltaic systems in Europe. Under review. Accessible via Deliverable 5.1, HyPErFarm project (URL)
[17] European Commission. Common Agricultural Policy (URL)
[18] HyPErFarm project. Pilot plants (URL)
[19] Agrivoltaics webtool (URL)

Agrivoltaics into existing farming practices and contribute substantially towards the EU's defossilization and climate neutrality goals

Policy Recommendations

EU Level:

- **Set specific standards on what qualifies as an APV system**: Currently, there is no universally accepted definition of Agri-PV in Europe. The frontrunners in the field of Agri-PV within the EU are Germany, France, and Italy, which have taken the initiative in developing standardization protocols and guidelines for Agri-PV implementations.[20,21,22] Taking inspiration from their efforts, the first steppingstone toward encouraging the widespread adoption of APV systems should be the establishment of a clear and stringent definition of what constitutes an APV system (taking into account EU related policies). Development of a Quality Standard, monitored by a third-party entity is also a requirement. This is imperative to prevent conventional PV projects from encroaching on fertile agricultural lands under the guise of APV systems. Ensuring that agricultural yields are not compromised should be a central consideration in these standards. Consequently, a project could be classified as APV if it meets certain benchmarks, such as maintaining a stipulated minimum percentage of crop yield in comparison to the yield in the absence of APV. Japan serves as a noteworthy example in this regard, where the Ministry of Agriculture, Forestry and Fisheries (MAFF) has enacted regulations stipulating that an agrivoltaic system can only be installed if the crop yield is maintained at a minimum of 80% of its original production levels.
- **Targeted financial support of APV**: For initiatives that meet the criteria for genuine APV systems (as elaborated in the point above), it is imperative that financial support be extended for a designated period. This approach mirrors the support historically provided to emerging sustainable technologies, including conventional PV systems. The infrastructure necessary for the dual utilization of land in APV systems diverges from that of traditional PV projects and may encompass elements like elevated mounting frameworks and semi-transparent solar modules. As the production of these components is yet to achieve economies of scale, their implementation is associated with higher costs compared to conventional PV systems. Consequently, the involvement of public institutions can be invaluable during the nascent stages of extensive APV deployment. This support can materialize in various forms, such as direct contributions via subsidized electricity tariffs or indirect incentives like tax reliefs linked to project investment costs and preferential loan conditions for such ventures. Such backing would substantially facilitate the initial phase of APV adoption until the technology evolves to become more cost-effective.
- **Streamlining regulatory and permitting processes**: The implementation of APV systems should not be stymied by inflexible regulatory protocols, such as onerous construction permitting procedures. Measures should be taken to expedite these processes, for instance, by creating catalogues of pre-approved system designs, thereby facilitating a fast-track approach for construction permits. Furthermore, it is essential to proactively identify and mitigate other potential regulatory obstacles, such as the implications of land use designation alterations when APV systems are integrated with agriculture. To do so, identification / classification of potential agricultural land for Agri-PV deployment through spatial planning and categorisation of land in terms of suitability that takes into consideration policies related to energy, agriculture, environment and biodiversity at EU and national level should be implemented. The processes for obtaining licenses and connecting to the electrical grid should be streamlined and expedited.
- **Avoiding conflicts with agricultural subsidies**: In the frame of the CAP measures, farmers receive agricultural subsidies, depending on their use of the land. Installing APV may negatively affect the farmer

[20] DIN SPEC 91434:2021-05 Agri-photovoltaic systems - Requirements for primary agricultural use (German Institute for standardization, 2022).
[21] Ministry of the Environment and Energy Security (MITE, 2022). “Guidelines on Agri-PV systems”
[22] Agency for the Ecological Transition (ADEME, 2021). “Characterizing solar PV projects on agricultural land and Agrivoltaism”

by not receiving the agricultural subsidies anymore. This needs to be avoided and framework conditions changed so that it is possible to install APV and still receive CAP subsidies.

- **Addressing access to grid issues**: Given that APV systems are intrinsically a highly decentralized form of electricity generation, their deployment is contingent upon access to the electrical grid. In instances where expanding the grid at the requisite pace proves unfeasible, alternative strategies warrant consideration. These alternatives may encompass incentives or support for decentralized energy conversion systems, such as converting electricity into green hydrogen, or fostering support for user cooperatives centred around extensive APV installations, which could include agro-industrial enterprises. This multifaceted approach ensures that the deployment of APV systems remains agile and adaptable, navigating the complex landscape of regulations and grid accessibility.
- **Promote APV innovation**: Fostering innovation in APV can be approached through a multitude of avenues at the EU level. This encompasses R&D grants to facilitate further research into APV systems, both at the farm level and in the realm of enabling technologies, such as advancements in photovoltaic technology, with the objective of optimizing the amalgamation of agriculture and solar energy generation. Additionally, support for domestic production of essential components can play a significant role.
  Up until the present, only a single specific call topic has been issued pertaining to the development of Agrivoltaic systems within the Horizon Europe research and innovation programme.[23] Moreover, the work programme for 2023 – 2024 does not encompass any call topics in relation to this subject. It is of paramount importance to create avenues for funding in order to catalyse the development of new APV pilot plants. This will pave the way for a more comprehensive understanding of the dynamics and performance of agricultural practices in conjunction with energy production through APV systems.
  The establishment of these pilot plants can serve as invaluable case studies, offering insights that can guide policymaking, support the creation of best practices, and ultimately contribute to the EU's goals for sustainable energy and climate action. Engagement with industry stakeholders, agricultural communities, and research institutions should also be prioritized to foster collaboration and knowledge sharing in the pursuit of refining and scaling of APV technology.
- **Awareness:** Raising awareness regarding the merits of APV systems should commence with the farming community at the foundational level and encompass all the stakeholders integral to the value chain, such as researchers, developers, manufacturers, and more. Aarhus University conducted a study through the HyPErFarm project where they created various “Personas” based on qualitative interviews to simply understand the key stakeholders’ perceptions of Agrivoltaics, as well as their needs, goals, and frustrations. This insight helps in developing tailored strategies for encouraging acceptance and smooth integration of these innovations.[24]
- Furthermore, actively showcasing APV technology through pilot projects encompassing a diverse array of crops, coupled with the arrangement of educational visits, should be encouraged. Informational campaigns, workshops, and accessible guidelines delineating the advantages of APV systems ought to be disseminated to increase the curiosity and interest of farmers and agricultural associations. Establishing a knowledge-sharing framework is crucial to capitalize on acquired experience, steering the successful adoption of APVs.
- However, awareness-building initiatives should not be circumscribed to the farming community alone. It can prove equally fruitful to engage wholesale purchasers of agricultural produce, such as supermarket chains. These entities can craft innovative marketing strategies for products cultivated in tandem with APV systems. Moreover, educating consumers and fostering a predilection for produce associated with APV technology could catalyse market demand. Similar to how consumers have gravitated towards specialized products like organic foods, they can be encouraged to prefer and seek out products cultivated through

[23] Novel Agro-Photovoltaic systems. TOPIC ID: HORIZON-CL5-2022-D3-01-06. (URL)
[24] Torma, G. & Aschemann-Witzel, J. (2023). Creating Personas: A Qualitative Multi-Stakeholder Approach to Explore Sustainable Innovation Perception. Accessible via HyPErFarm website (URL)

sustainable APV systems. This multifaceted approach bridges the gap between technology, agriculture, commerce, and consumer preference, thus bolstering the ecosystem for APV adoption.

Member state Level:

- Dedicated capacity targets for Agri-PV systems in the Member State national plans and policies should be set from governments.
- Land use designation changes is sensitive, as some Member States are open and flexible, while for others landscape preservation is of primary importance and the framework is strict.
- In Greece, Agri-PV is regulated by the national law 4513/2018, according to which, Agri-PV can be implemented in two ways: (i) by installing semi-transparent or opaque PV modules on greenhouses or other agricultural buildings, which can generate electricity for self-consumption or feed-in to the grid. The PV modules can also provide shade, protection and microclimate control for the crops and (ii) by installing PV modules on farmland, which can generate electricity for self-consumption or feed-in to the grid. The PV modules can also allow for dual use of land, where crops can be cultivated under or between the modules. The law also provides financial incentives for Agri-PV projects, such as: (i) guaranteed feed-in tariff (FIT) for 20 years for projects up to 500 kWp; (ii) premium tariff for projects above 500 kWp that participate in the electricity market; (iii) reduced property tax for projects up to 1 MWp; (iv) reduced connection fee for projects up to 1 MWp.
- In Italy , based on the article 11 of the decree-law of 1 March 2022, n. 17, converted, with amendments, by law 27 April 2022, n. 34, after paragraph 1, the following is added: Photovoltaic plants located in agricultural areas, if located outside protected areas or belonging to the Natura 2000 network, subject to the definition of the suitable areas referred to in article 20, paragraph 1, of legislative decree 8 November 2021, n. 199, and within the limits allowed by any prescriptions where located in areas subject to direct or indirect landscape constraints, are considered artifacts instrumental to agricultural activity and are freely installable if they are made directly by agricultural entrepreneurs or by jointly owned companies with electricity producers to which the company or business branch is conferred by the same agricultural entrepreneurs to whom it is business management activities are reserved except for the technical aspects of plant operation and energy transfer and the following conditions are met: (i) The solar panels are placed above the plantations at a height equal to or greater than two meters from the ground, without concrete foundations or difficult to remove; (ii) The implementation methods provide for their effective compatibility and integration with agricultural activities as a support for the plants or for parcelled irrigation systems and protection or partial or mobile shading of the underlying crops for the purpose of the simultaneous creation of monitoring systems, to be implemented on the basis of guidelines adopted by the Council for agricultural research and analysis of the agricultural economy, in collaboration with the Energy Services Manager (GSE); (iii) The installation is in any case subject to the prior consent of the owner and of the farmer, in any capacity as long as it is onerous, of the fund".

Expected Impacts

- The APV concept could make a significant impact in different production systems, including protected agriculture in greenhouses and the open-field cultivation of a variety of crops. Primary interest would be the open-field cultivation of fruits and vegetables, as well as viticulture, due to factors such as their widespread presence in many regions, the good adaptability of several of them to partial shading, the high value of several of them, and the large losses they incur annually due to adverse weather phenomena (e.g., hail).
- The cultivated land in the EU devoted to these crops exceeds 6.5 M ha, of which we can consider 20% as available for APV deployment, owing to factors such as solar potential, capital availability, technical reasons, and farmer conservativeness. Rolling out APV systems on 8 k ha of agricultural land annually, with a capacity of 5.5 GWp, would conserve more than 5 k ha of land annually that would have to be devoted to single-use

ground-mounted PV in order to install the same power; the capacity of 5.5 GWp could correspond to adding 6 TWh/yr of renewable energy to the EU energy system every year.

- Rather than only selling energy to the grid, APV systems could, through the support of self-consumption or direct-selling practices, assist in assist on avoiding utility grid overloading and improving its resilience. In addition, farm applications such as water pumping for irrigation, charging electric agricultural vehicles and tools, drying or cooling commodities equipment could be served. Also, supplying energy to adjacent buildings or electric loads (in agreement with the respective owners) to form a local microgrid and serving domestic and commercial energy needs of an energy community (potentially charge battery arrays for this purpose) could be another application of APV.
- Conventional PV panels or semi-transparent modules seem to have good potential to assist on simultaneous food and energy production. Open spaces between conventional PV systems could be cultivated with either annual or perennial crops to bring agricultural value to existing ground mounted PV systems. Conventional PVs could be also mounted on farmers' auxiliary buildings and warehouses, either on the rooftop (optimal inclination leading to maximum performance) or in the side surfaces.

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