Case study collection:

Agrivoltaics

Agrivoltaics is the combining of solar panels to generate electricity with agriculture – arable, horticulture or livestock. Agrivoltaic systems are designed and built to enable farming and food production to occur simultaneously with energy generation . These systems differ from conventional solar farms in which electricity is usually the sole output.

This collection of case studies explores agrivoltaics on farms across Europe and is part of a Decision Support Tool (DST) for farmers and their advisors to explore whether there is potential to integrate food and energy on their farm, particularly through agrivoltaics and biogas

The DST contains three main parts:

1. An Open Access (free) Online Course "Integrating Food and Energy Production on Farmland" introducing the technologies and concepts behind renewable energy generation on farmland
2. An Audit Tool – to evaluate the current environmental, social, economic, technical and governance situation of a farm and thus to support farmers and their advisors in deciding which path to follow if they are considering producing renewable energy via biogas or agrivoltaics.

3. A Transition Tool – a collection of checklists, case studies and a partial budgeting tool for farmers and advisors who want to introduce agrivoltaics, biogas or both on their farm. It outlines the factors that need to be considered when introducing these technologies and provides links to supporting information and resources.

Find all these elements at *https://value4farm.eu/decision-support-platform/*

The case studies have been developed from published research and discussions with farmers and researchers. Links to further information are available for each case study.

Case Studies

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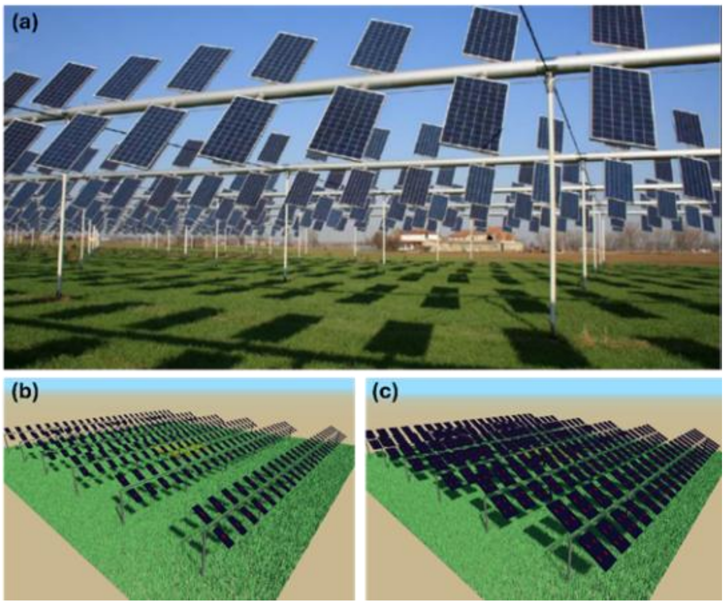
Agrivoltaics and Maize in Northern Italy

Location:	Northern Italy, Emilia Romagna Region Average regional temperatures: -1°C to 30°C Average regional monthly rainfall: 28mm - 90mm
Type of study:	Modelling / Simulation Using modelling and climate data to explore how different types, arrangements and positioning of solar panels impact on electricity generation, crops and soils
Type and set-up of panels:	Panels were raised above the ground and were either static or solar tracking. Raised panels enabled agricultural equipment to be used under and between the panels. Panels were set up at different densities (different m^2 of panel per m^2 of ground) to explore the impact on crops. The image below shows the raised structure, the two different panel densities and the shading caused by the panels.  Image credit: *Value4Farm D1.6 and D2.8*
Crops grown with panels:	Maize – rainfed, no irrigation
Impact on crops:	The highest maize yields were under full light (no panels). In rainfed conditions (no irrigation) average maize yields were higher under scenarios where panels were used. The variation in maize yield (on a year-to-year basis) was also lower with solar panels present. The shading provided by the solar panels has the potential to stabilise maize yields in this scenario.

Sustainability benefits:	When water is not limited, crop yields were lower under the agrivoltaics. However, where rainfall and water availability was limited, for example under drought conditions, maize yields were higher and more stable under agrivoltaics. Agrivoltaics reduced direct radiation (sunlight) to the crops and soil, which can reduce evaporation, and affect average soil temperatures and water balance. In a changing climate, with increasing potential for drought, agrivoltaics could have a role to play in the simultaneous production of renewable energy, saving water and supporting crop yields.
Electricity generation:	Average electricity generation per m^2 of panel over one year from different agrivoltaic scenarios, panels were at two different densities and either static or tracking: • Static - 11.73 $kWh \cdot m^{-2}$ to 43.43 $kWh \cdot m^{-2}$ • Tracking - 17.42 $kWh \cdot m^{-2}$ to 64.04 $kWh \cdot m^{-2}$
Land use:	Combining crops and solar panels increased land productivity. The Land Equivalent Ratio (which describes the relative land area required in an area under monoculture (single crop) to produce the same yield as an area under intercropping or polyculture (e.g. agroforestry, combining crops and trees, or in this case crops and energy)) was calculated for all the scenarios, and in all cases showed that intercropping - combining maize and solar panels – was a more productive system than the separate production of maize and electric energy from ground mounted solar panel systems.
Challenges:	Maize grain yields were lower when it was grown under solar panels, potentially due to shading and solar radiation reduction. However, this occurred in conditions where water availability was not limited, when water was limited, average yields were higher for crops grown with panels.
Clickable link:	*Agrivoltaic systems to optimise land use for electric energy production*

Agrivoltaics and Tomatoes from Northern to Southern Italy

<table>
<tr><td>Location:</td><td>Italy – range of locations, from North to South:
Piacenza; Grosseto; Foggia; Oristano and; Agrigento</td></tr>
<tr><td>Average temperatures and rainfall:</td><td>Piacenza: -1°C to 30°C; 36mm – 90mm
Grosseto: 3°C to 30°C; 25mm – 83mm
Foggia: 3°C to 33°C; 17mm – 50mm
Oristano: 7°C to 30°C; 3mm – 55mm
Agrigento: 9°C to 28°C; 3mm - 64mm</td></tr>
<tr><td>Type of study:</td><td>Modelling / Simulation
Using modelling and climatic data to explore how different types, arrangements and positioning of solar panels impact on electricity generation, crops and soils.</td></tr>
<tr><td>Type and set-up of panels:</td><td>Mixed set-ups, including vertical, overhead, solar tracking and static. Panels could also be mono-axial or bi-axial (tracking the sun on one or two axes). The image below shows the range of panel alignments and associated shading.

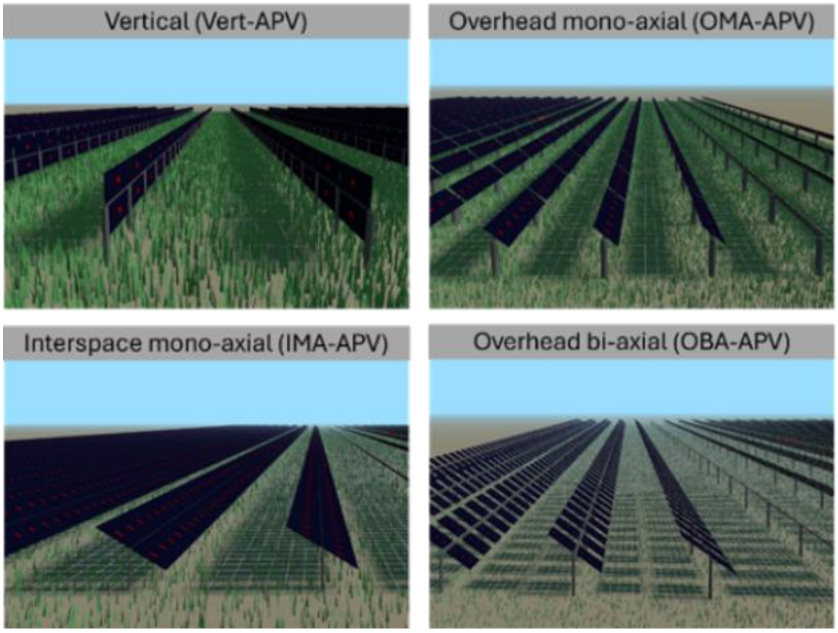
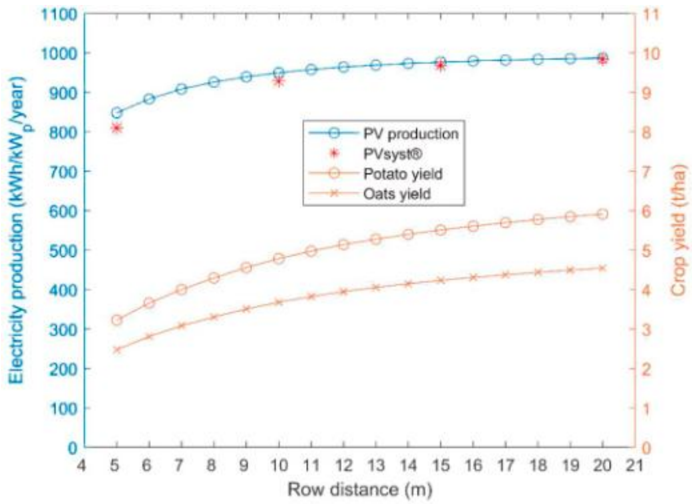



Image credits: *Simulation-Based Decision Support for Agrivoltaic Systems*</td></tr>
<tr><td>Crops grown with panels:</td><td>Tomato</td></tr>
</table>

Impact on crops:	There were positive and negative impacts on crop yields. Depending on the location and the type of agrivoltaic configuration used (raised vs. Horizontal panels, mono-axial vs. bi-axial, distances between rows), tomato yields were reduced by between 10 and 40%. Yield reduction was due to both shading by the panels and reduced land area available for planting and harvesting due to panels and mounting structures. The set-up of panels, including distance between panels and horizontal or vertical placement had varied impacts on crop yields with interspaced mono-axial panels (which sit closer to the ground than overhead panels) having higher shading and higher yield reductions However, the modelling also demonstrated that under very dry conditions, yields under solar panels could increase.
Sustainability benefits:	Water use efficiency was positively influenced by shading from the solar panels. In warm climates and in water scarce conditions crops grown in agrivoltaic scenarios showed lower yield reductions than those crops grown in full-light conditions.
Electricity generation:	Electricity generation varied according to location and agrivoltaic configuration. The highest outputs were from the most southern site (Agrigento) and the lowest from the most northern (Piacenza). The most effective configuration for electricity generation was interspaced mono-axial panels with a 10m pitch (gap between rows): • Agrigento - 1700 MWh ha^{-1} $year^{-1}$ • Piacenza - 1268 MWh ha^{-1} $year^{-1}$
Challenges:	Balancing need for sunlight between solar panels and crops, finding the optimum density and configuration of panels to both generate electricity and not significantly reduce crop yields. This case study demonstrates the benefits of modelling or simulations in deciding how to set-up agrivoltaics. A range of agrivoltaics can be trialled - distances between rows, tracking or static, raised or vertical mono or bi-axial - to see how shading is distributed and explore the impacts on crop growth and yield. Models can use a variety of climatic data for the region – such as rainfall, temperatures, solar radiation – and use them alongside calculated “unknowns” such as the shade cast by panels, to explore the impact this will have on crop yields and soil water.
Clickable link:	*Simulation-Based Decision Support for Agrivoltaic Systems* (Open access – freely available)

Vertical Agrivoltaics with Potatoes and Oats in Sweden

Location:	Kärrbo Prästgård, Västerås, Sweden. Average monthly temperatures: -6°C to 21°C Average monthly rainfall: 13mm - 69mm
Type of study:	Modelling Using modelling and climatic data to explore how different types, arrangements and positioning of solar panels impact on electricity generation, crops and soils.
Type and set-up of panels:	Vertically mounted panels, with photovoltaic modules on both sides. Panels are static and do not track the sun. Panels set up in rows at different distances, from 5m to 20m apart, to explore the impact on crops 
Crops grown with panels:	Oats, Potatoes
Impact on crops:	With the row distance between panels at 9m for oats and 11m for potato, yields were 70% of those found in open field conditions. Crop yields were reduced, but the reduction varied depending on the spacing between the rows. Yields of both oats and potato reduced by around 50% when panel rows were 5m apart. When panel rows were 20m apart oat yields were reduced by around 8% and potato yield by around 13%. Changes in how panels were positioned, for example orientating panels more towards the south or the east, also impacted shading and crop yields.
Sustainability benefits:	While shading from the panels reduced yields, it also has the potential to increase resilience in food systems during drought. The supporting structures and panels reduce the land available for planting crops, but provide areas of increased biodiversity which can be beneficial for pollinators.

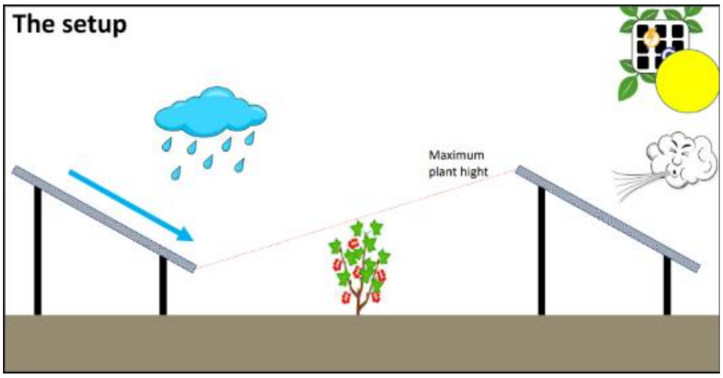
Electricity generation:	Electricity generation varied depending on the distance between the rows of panels • 5 m rows – approximately 850 kWh/kW$_p$/year (kWh produced per kW of panel per year) • 20m rows – approximately 970 kWh/kW$_p$/year The graph below shows the relationships between row distance, electricity production and oat and potato yields.  Image credits: *Optimisation of vertically mounted agrivoltaic systems*
Challenges:	Land close to the vertical panels could not be used to grow crops, as agricultural machinery could not access it for harvesting, approximately 10% of the land was inaccessible. However, this provides a habitat for pollinators, pest control species and biodiversity which can lead to positive effects on crops and crop yields. This model used data from one year to explore the impact of solar panels on land use and crop yields. The study authors highlight the need to consider the impact of these technologies over multiple years, so that the optimum layout for panels with different crops and under different climate scenarios can be evaluated.
Clickable link:	*Optimisation of vertically mounted agrivoltaic systems* (Open access paper – freely available)

Vertical Agrivoltaics and Ley Grass in Sweden

Location:	Västerås, Sweden Average monthly temperatures: -6°C to 21°C Average monthly rainfall: 13mm - 69mm
Type of study:	Experimental and modelling Using modelling, data collected from a research site was used to explore how different types, arrangements and positioning of solar panels impact on electricity generation, crops and soils.
Type and set-up of panels:	Vertically mounted bi-facial panels (solar panels on both sides of the structure). Distance of 10m between rows.  Image credits: *Experimental results, integrated model validation, and economic aspects of agrivoltaic systems at northern latitudes*
Crops grown with panels:	Ley grass The field has been in grass production for several years and also contains a wide variety of legumes and herbs (many are perennial). It is maintained with an organic farming approach.
Impact on crops:	There was no difference in yields between the ley grass grown under the agrivoltaic system to that grown in the reference field with no solar panels. The solar panels reduced solar radiation to the ground by (on average) 25%. However, the Leaf Area Index (LAI) of the ley grass grown under the panels had increased by approximately 12% (compared to those in open field), meaning that in more shaded conditions leaf area had increased, enabling crops to absorb more sunlight and maintain yields. Overall, yields from the agrivoltaic experimental area decreased by approximately 10% due to the unused land next to the solar panels.

Sustainability benefits:	Soil moisture was higher at certain soil depths under the agrivoltaic systems compared to the open field. In drought or low water conditions this may help to maintain crop yields. This agrivoltaic system (combining crop rotations and energy production) is more profitable than a conventional crop rotation, supporting economic sustainability on farm.
Electricity generation:	In the first year, electricity production was 1067 kWh/kW_p The buying and selling prices of electricity had a significant effect on the value of the project and the value of installing the agrivoltaics.
Land use:	There was some loss of land which could not be harvested, but the combining of crops and agrivoltaics was estimated by the study authors to be approximately 30 times more profitable over a 30-year period, than a conventional crop rotation alone in Sweden.
Challenges:	Land loss and yield loss, as the farmers were unable to harvest close to panels, a proportion of the crop (approximately 10%) was lost. Some countries have in place, or are considering adopting, policies and regulatory requirements that set targets for crop yields in agrivoltaic set-ups. Modelling and simulations, such as described in this study, can support this through pre-installation modelling and estimation of crop yields.
Clickable link:	*Experimental results, integrated model validation, and economic aspects of agrivoltaic systems at northern latitudes* (Open access – freely available)

Agrivoltaics and Blackcurrants in Denmark

Location:	Ringkøbing-Skjern municipality, Denmark Average monthly temperatures: -1°C to 20°C Average monthly rainfall: 32mm - 71mm
Type of study:	Case study of practice – solar panels installed in 2015, blackcurrants planted in a section of the solar facility in 2022 / 2023
Type and set-up of panels:	Solar panels over approximately 32 hectares, with 6 hectares of this area planted with blackcurrants between the panel rows. Panels are mounted close to the ground and are static. The images below show the panel set-up and the planting.   Image Credits: Ole Green
Crops grown with panels:	Blackcurrants Blackcurrants were chosen as they are naturally shade tolerant.

Impact on crops:	The panels are set up to optimise the amount of solar radiation they receive and the electricity they generate. This has led to increased shading to the plants and a reduction in yield, but yields are increasing and the plants are sheltered from the wind. Plant growth is slower compared to those grown in open field systems, but the plants are robust.
Sustainability benefits:	Production of renewable energy and increased land use efficiency, land that was solely used to generate electricity now also produces food. There is improved biodiversity around the panels and groundwater resilience has improved.
Electricity generation:	16MW agrivoltaic system, producing approximately 16,000 MWh electricity annually
Challenges:	Regulations relating to land use and planning permissions for solar panels on farmland, both for solar parks and agrivoltaic installations. Negative views from local residents on the visual impact of solar panels and loss of land from agricultural systems, however demonstrating how crops can be combined with the solar panels has helped to mitigate this. While the blackcurrant plants are growing well, yields on those grown with the solar panels are lower than those grown in open fields. This could be due to limits on the use of manure and slurry spreading in cropping systems (leading to lower nitrogen in the soil), or potentially due to shading. Agrivoltaics have lower income than solar panels alone, due to the set-up, so in this system, time is needed to see financial benefits. There may also be challenges with standard agricultural equipment not able to be used in agrivoltaic systems.
Clickable links:	More from famer Ole Green in a series of short films in the course *Integrating Food and Energy Production on Farmland* *Presentation at HyperFarm event - How I planted 6 ha of berry bushes*

Cultivating pears under semi-transparent panels in Belgium

Location:	Bierbeek, Belgium
Average temperatures and rainfall	Average regional temperatures: 1°C to 22°C Average regional monthly rainfall: 34mm - 54mm
Type of study:	Pilot installation on commercial farm - research
Type and set-up of panels:	Semi-transparent, static solar panels mounted on existing hail net supports. Panels are set in pairs 4.2m above the ground (above the trees), with 3 rows, 21m in length. Photos below show the panels and site, with test site of panels surrounded by hail nets.   Image credits: *Agrivoltaic cultivation of pears under semi-transparent panels reduces yield consistently and maintains fruit quality in Belgium*

Crops grown with panels:	Pears, orchard setting Trees planted in 2017, planting distance of 1m, and inter-row distance of 3.3m
Impact on crops:	Trees and blossom were not damaged by nighttime spring frosts, possibly due to slightly increased air temperatures under the panels. Panels had a shading effect, reducing ambient temperatures, light stress to the trees, and sunburn of fruit under the panels Fruit drop (shedding of developing fruit before it reaches maturity) was not affected by panels, nor was individual fruit weight or diameter. There was also no impact on fruit quality parameters, including fruit firmness and starch index. However, total fruit yield was reduced by around 15%.
Sustainability benefits:	The shelter provided by the panels, increasing ambient temperatures and providing shade / shelter, could reduce the need for heating systems and irrigation and in turn reduce power use. Panels could also reduce the need for hail nets, reducing plastic use.
Electricity generation:	Small research system producing 12.74 MWh per year
Challenges:	Reduced light levels in the canopy potentially leading to a reduction in fruit yield of around 15%
Clickable link:	*Agrivoltaic cultivation of pears under semi-transparent panels reduces yield consistently and maintains fruit quality in Belgium*