AGROPHOTOVOLTAICS AND OTHER OPPORTUNITIES FOR GREEN ENERGY TRANSITION IN AGRICULTURE

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Abstract

Renewable energy sources are one of the key tools for achieving a carbon-neutral European Union by the year 2050. A significant portion of emissions at the European Union level is caused by agricultural and forestry activities. To equip farmers and foresters with knowledge, technology, and tools, the ECOLOOP project is being implemented at the European Union level. With its innovations, it enable progress in the field of sustainable development in agriculture and forestry in Europe. The innovations are being tested at four pilot locations in Slovenia, Spain, Estonia, and Bulgaria. In addition to bioenergy plants, the project is developing agrophotovoltaic systems, which are an important renewable energy technology, not only do they have an energy impact but also because, with the appropriate device installations, agricultural and forestry processes can also be improved. Since agrophotovoltaic systems represent a significant financial burden for investors, various support schemes are offered at the EU level, with particular emphasis on the Contracts for Difference system and the Power Purchase Agreement system.

Keywords: renewable energy sources, agrophotovoltaics, RES Support Schemes, ECOLOOP Project

AGROFOTOVOLTAIKA IN OSTALE PRILOŽNOSTI ZA ZELENI PREHOD KMETIJSTVA

Povzetek

Obnovljivi viri energije so eno od ključnih orodij za nastanek ogljično nevtralne Evropske unije. Veliko izpustov na ravni Evropske unije povzročijo tudi kmetijske in gozdarske dejavnosti. Z namenom opremiti kmetovalce in gozdarje z znanjem, tehnologijo in orodji se na nivoju Evropske unije izvaja projekt ECOLOOP, ki s svojimi inovacijami omogoča napredek na področju trajnostnega razvoja kmetijstva in gozdarstva v Evropi. Inovacije se testiranjo na štirih pilotnih lokacijah v Sloveniji, Španiji, Estoniji in Bolgariji. Poleg bioenergetskih naprav v sklopu projekta razvijajo tudi agrofotovoltaične sisteme, ki so pomembna tehnologija obnovljivih virov energije, ne zgolj zaradi samega energetskega učinka, temveč tudi zato, ker lahko s primerno namestitvijo naprav optimiziramo same kmetijske in gozdarske postopke. Ker so agrofotovoltaični sistemi veliko finančno breme za investitorje, se na ravni Evropske unije ponuja več različnih podpornih shem, pri čemer se izpostavljata predvsem sistem Pogodbe za razliko in sistem Pogodbe o zagotovljenem odkupu električne energije.

Ključne besede: obnovljivi viri energije, agrofotovoltaika, podporne sheme obnovljivih virov energije, projekt ECOLOOP

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1 INTRODUCTION

In recent years, the European Union (EU) has been actively encouraging agricultural and forestry stakeholders to use renewable energy sources (RES) and adopt sustainable solutions to address environmental challenges. Weather extremes, rising temperatures, and other issues faced by farmers and foresters are a consequence of greenhouse gas emissions, increasing energy consumption, and depletion of natural resources. Agricultural activities also contribute significantly to the production of greenhouse gases. Therefore, various EU-level projects are being implemented to provide farmers and foresters with the necessary knowledge and technologies to facilitate a sustainable transition while incorporating RES. Agriphotovoltaics (APV) is considered one of the most suitable and agriculture-compatible RES technologies and will be implemented as part of several pilot installations within the ECOLOOP project, whose main goal is to provide tools, knowledge, and business models for farmers and foresters at the EU level. The article is structured as follows: after the introduction, the European ECOLOOP project promoting the green transition of rural areas is presented, followed by descriptions of the project's pilot locations. The article continues with a brief overview and classification of APV, its impact on crop growth, and soil cultivation. The following chapter presents future guidelines for operational support schemes to which APV units and other RES units will be eligible in the coming years. The article concludes with a summary and references.

2 PROJECT ECOLOOP

The ECOLOOP project (0) is implemented under the Horizon Europe programme, which funds research and innovation in the field of the European Union (EU). The consortium includes 14 partners from 4 EU countries, as seen in Figure 1 below. The project aims to equip farmers and foresters with the tools, knowledge and business models needed to manage land and waste efficiently in agriculture and forestry.

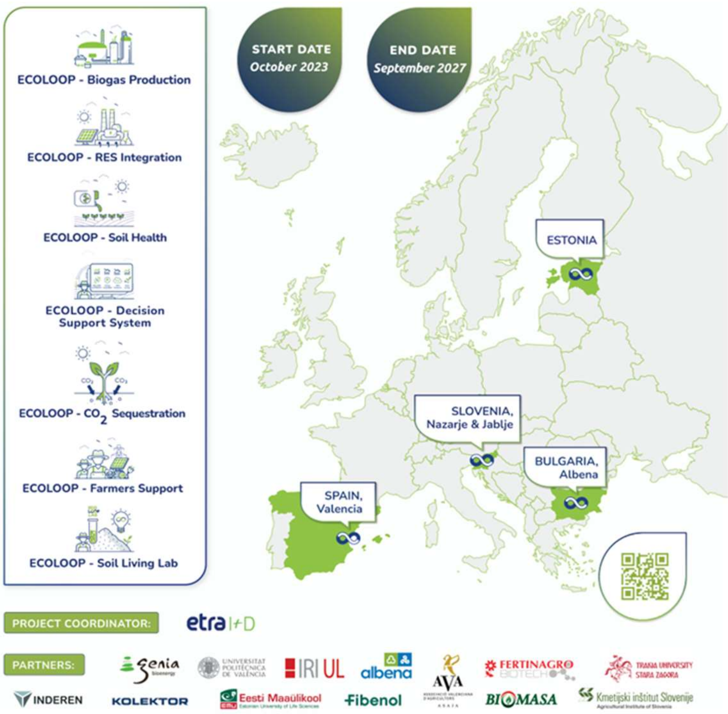

Figure 1: Project ECOLOOP

2.1 ECOOLOP Innovations

The ECOLOOP project introduces innovative solutions to promote the use of decentralised RES in rural areas, focusing on the efficient integration of solar and geothermal energy with different forms of bioenergy such as biogas and biofuels. One of the key objectives of the project is to develop new and upgrade existing processes, such as slow modular pyrolysis, which increases the efficiency of biogas production from agricultural and forest by-products or waste and allows the simultaneous use of geothermal and solar energy.

The main objective of the ECOLOOP project is to optimise processes for bioenergy production and to develop bio-based products from agricultural and forestry waste, which will contribute to reducing the world's dependence on fossil fuels and its carbon footprint. The project also includes, among other things, the development and application of an advanced method for the utilisation of digestate to be used as organic fertiliser and the design of protocols and strategies for carbon capture and sequestration, which will further contribute to reducing emissions.

The project promotes circular and sustainable practices in agriculture and forestry using the latest advanced technologies and business models. Improving biodiversity, soil quality and groundwater is also an important aspect of this use. To support regional development in rural areas, ECOLOOP is developing a comprehensive framework combining legislation, different technologies and business models. The project introduces new strategies and financial incentives that also encourage small farmers and foresters to adopt innovative technologies, thereby increasing renewable energy production, and reducing energy costs and greenhouse gas emissions. With the planned results, the project contributes to the 2030 target of producing around 35 billion m3 of biogas and biomethane in the EU, representing a market share of 10%. By 2050, this volume is expected to reach 95 bcm, which could cover 30-40% of the gas market share. The projected growth creates opportunities for 420,000 jobs by 2030 and more than 1 million jobs by 2050 in Europe.

3 ECOLOOP PILOT LOCATIONS

The solutions developed in the framework of the ECOLOOP project are tested in four large-scale demonstration pilots which are being carried out in Spain, Slovenia, Estonia and Bulgaria. These pilots cover entire value chains and include a wide range of crops, plantations and trees in the agroforestry and forestry sectors. In addition, they address different types of energy sources and technologies and take into account diverse climatic, geographical and socio-economic conditions. The different sizes of the sites and activities involved will facilitate the dissemination and replicability of the results and enable their eventual market uptake.

In order to effectively implement these demonstration cases, the project consortium includes different partners who ensure access to the key infrastructures needed to carry out the demonstrations. The ECOLOOP demonstration activities take place at several levels, ranging from small, specific scenarios to larger and more complex demonstrations of the project solutions in broader areas. Each demonstration cover different aspects of the project, testing the solutions in different circumstances and under different climatic conditions.

These demonstration activities last for more than one year, allowing for comprehensive testing of solutions in all seasons. The following sections outline the specific activities and infrastructures involved in each demonstration site.

3.1 Slovenia

The Slovenian pilot project comprises two sites. The first is located at the Nazarje Biomass Centre, which is located in an industrial zone. Its main activity is the conversion of wood waste, including waste from the timber industry and sawmilling, into woody biomass. This biomass serves as a key source for the production of electricity, heat and wood fuels. The production process, which includes the processing, preparation, transport and feeding of materials into the wood gasifiers - the components of the biomass power plant - is fully automated and monitored in real-time via a central control system. The operation of the plant is based on pyrolysis, where wood chips and pellets are converted into a combustible gas called "wood gas", which is then used in a combined heat and power (CHP) system. The current infrastructure consists of 12 modular CHP units, which together provide 550 kWe of electrical power and 1 200 kWth of thermal power. In addition, there is a wood chip boiler with a capacity of 4,900 kWth and a wood biomass storage facility.

The annual production includes approximately 150 000 nm^3 of naturally dried wood chips, 25 000 nm^3 of technically dried wood chips, 15 000 tonnes of pellets and 500 tonnes of wood briquettes. The Centre plans further investments, including an additional 500 kWe CHP unit, a second 300 kWe unit, two new wood chip boilers with a total capacity of 5,500 kWth, a new wood chip storage, a photovoltaic power plant, charging stations for electric vehicles and battery storage system (BESS).

The second pilot site is located at the Infrastructure Centre Jablje (IC Jablje), owned by the Agricultural Institute of Slovenia (KIS), where a modular micro-biogas plant installed by KIS is upgraded with a biomethane production unit. The upgrade includes biogas purification and conversion to biomethane, as well as a filling station for tractors that will be converted to use biomethane as a fuel. The micro biogas plant includes an anaerobic digester (AD) with a capacity of 24 m^3 and a biogas storage tank with a capacity of 18 m^3. The system also includes a CHP unit with a capacity of 7 kWe of electricity and 16 kWth of heat. The biomethane produced is stored and used as an environmentally friendly fuel to power agricultural machinery.

3.2 Estonia

Estonia is located in the boreal climate zone, where forests cover around 50% of the country. Woody biomass, which includes low-quality wood and waste from logging and the timber industry, accounts for around 25% of RES energy production, playing a key role, especially in regional heating systems. The pilot site in Estonia consists of a network of short-rotation forest plantations and a pilot biorefinery for the production of biomaterials. This network includes 70 different sites with different soil types, forest management and fertilisation practices.

The plantations include several species of deciduous trees, including hybrid aspen, silver birch and black alder. These tree species can increase resilience to climate change by replacing climate-sensitive spruce trees and reducing the pressure on native forests to be harvested. The plantations are planted on abandoned agricultural land and the results from the pilot areas are be taken into account in the design of wider forestry practices in Estonia, depending on the available land and soil types.

The pilot sites provide key data on growth and soil quality that are fed into modern growth and yield models. These models form the basis for a carbon calculation tool, which operate as an open-access web-based platform and allow the assessment of benefits such as carbon capture and sequestration, carbon credits and financial gains.

Estonia's leading biorefinery Fibenol, located in Imavero, uses advanced Sunburst technology to convert more than 90% of wood residues into new biomaterials such as lignin, wood sugars and special cellulose. The pilot plantations are the basis for analysing the potential of using woody biomass as RES for the production of these biomaterials. The biorefinery tested at least three new wood species grown on different soil types to assess their potential for the sustainable production of biomaterials.

The ECOLOOP demonstration activities allow an in-depth analysis of how the composition of wood from new fast-growing short-rotation forest plantations affects the properties of low-carbon biomaterials such as lignin, wood sugars and specialy cellulose, and how they can be produced with minimal environmental impact. The biomaterials produced replace fossil resources in industries such as biochemicals, building materials, packaging, cosmetics and pharmaceuticals. The raw material used in this process is second-generation wood residues from sustainably managed forests. FIBE contributes to an energy-efficient and sustainable cascade of biomass use, which reduces the environmental impact and increases the use of renewable materials in various sectors.

3.3 Spain

The Spanish pilot area is located in the district of L'Horta Sud, near Valencia, known for its rich agricultural tradition. The pilot aims to integrate renewable energy sources with modern agricultural practices, to create a sustainable energy community. Key components include:

- **AFV Systems:** a combination of agriculture and PV technology to support the cultivation of subtropical, vineyard and horticultural crops.
- **Geothermal Energy:** Harnessing heat from the underground for heating, air conditioning and water heating within APV structures, mushroom plantations, fruit storage and cold storage.

The Horta Sud Energy Community plans to hybridise AFV and geothermal energy, with solar panels powering a heat pump that harnesses heat from the subsoil for a variety of applications. This technological combination improves production by maintaining stable temperatures, which prevents harmful effects on the plants. The current infrastructure in the pilot area includes 120 m^2 of double-sided PV panels with an annual theoretical production capacity of 105 MWh, installed both on the ground and on the roofs of existing buildings.

In addition, a biogas plant is set up in the nearby town of Beniparrell, which processes 5 to 6 tonnes of agricultural waste per day, including 4 to 5 tonnes of fruit and vegetable residues, on an area of 800 m^2. The pilot plant is expected to produce 7 to 8 Nm^3 of biogas per hour. An innovative process for upgrading biogas to biomethane suitable for vehicles is tested at the laboratory level using hydrophobic membrane technology, which offers a modular solution for upgrading biogas and is particularly suited to smaller anaerobic digesters in rural areas.

The bio-fertilisers produced from the digestate of the biogas plant are tested on the 30-hectare Finca Sinyent experimental farm, which is equipped with advanced irrigation systems. On this farm, which is dedicated to experimental testing, the biofertilizers are tested on a variety of crops, including vegetables and kakis, to assess their effectiveness on different types of crops.

3.4 Bulgaria

Albena, the largest tourist resort in Bulgaria, is located in the Dobrich region, in the municipality of Balchik, on the northern Black Sea coast. This region, which covers 4,720 km², is key to Bulgarian agriculture, with 81% of the land area being farmland, mainly growing wheat, barley, sunflowers, oilseed rape and maize. Bulgaria is also the world's leading producer of lavender, lavender oil and rose oil. Albena aims to develop a local circular economy, bringing together different business sectors such as agriculture, bioenergy, real estate, tourism and health services.

The pilot area includes two key strategies to develop a sustainable business model based on RES. Under the ECOLOOP project, Albena is retrofitting existing greenhouses using PV technology to make the greenhouses smart and enable remote heat management. This technological upgrade increases the number of production cycles while reducing CO_2 emissions. The PV provides all the electricity needed for the pilot area, while plans include the expansion of capacity for new greenhouses, mushroom houses and stables. Thermal energy from the existing biogas plant helps to regulate the optimum temperature in the greenhouses, increasing productivity, reducing costs and contributing to lower CO_2 emissions.

The biogas plant in the Momchil area processes 2,200 tonnes of food waste, 1,000 tonnes of manure and 12,000 tonnes of maize silage annually, producing 6,500 MWh of electricity and 520 MWh of heat power. Thermal energy is essential to maintain optimal conditions in the greenhouses. In addition, the biogas plant contributes to the circular economy model by reducing waste and improving soil quality through the use of biogas by-products.

In collaboration with the University of Thrakia, Albena is carrying out an analysis of agricultural and organic waste to increase its efficiency in biogas production. The aim is to reduce dependence on maize silage to include more agricultural waste and to explore new crops with high potential for biogas production that have not been used in Bulgaria. Both objectives follow Albena's broader strategy to create a self-sustaining circular economy based on RES and ensure the sustainable development of the region.

4 AGROPHOTOVOLTAICS

APV systems link agriculture to power generation, representing an innovative and sustainable approach to the challenges of food and renewable energy production. The integration of photovoltaic (PV) power plants with agriculture promotes sustainable farming and helps to achieve environmental goals. One of the key advantages of AFVs is the optimisation of land use by producing food and electricity simultaneously, improving the efficiency of the use of natural resources such as land and water. AFV systems are in line with EU environmental objectives, including the European Green Deal, climate legislation and the RES Directive. AFV systems increase the resilience of agriculture to weather impacts by creating a more stable micro-environment through shade and protection from extreme conditions such as heat, frost and hail. This reduces variations in crop yields and improves productivity and profitability. AFVs serve to help farmers adapt to climate change. There are two main types of AFV systems: the first integrated on specific structures and the second installed on greenhouses, where the systems can incorporate high-tech tilting PV modules for higher efficiency depending on needs and climate.

AFV systems are also divided into open and closed designs. Open systems include PV on different structures to allow for the simultaneous implementation of agricultural and RES activities. Closed systems include PV plants on greenhouses, which are primarily used for growing plants (0).

4.1 Types of APV systems

Based on the design, presented in Figure 2, the APV systems can be classified as:

- **Elevated APV system**: it allows smooth soil tillage, protects plants from the weather and creates a microclimate that can have a favourable effect on growth. The high structure does not interfere with machining and the PV modules are positioned at different angles and densities.
- **The interspace APV system** uses low structures, which prevents tilling of the soil underneath, so farming is carried out between rows. This design does not provide the same level of shading and shielding compared to an elevated system.
- **The vertical APV system** includes upright structures with panels, which improves profitability due to the ease of construction. They do not interfere with ground treatment and, given the spacing, the power generation is comparable to conventional systems. It is recommended to use east-west oriented double-sided panels, as they take advantage of the morning and afternoon sun. A vertical layout is ideal as the electricity production coincides with the time of peak consumption. Even more efficient is the use of a single-axis tracking mechanism that maximises production and adapts operation to the needs of the plants and cultivation (0).
- **The greenhouse APV system** has the PV installed on the roof of the greenhouse, which allows the power supply to operate and control the greenhouse. It is important to minimise shading, which can have a negative impact on crop yields. Conventional panels integrated into the roof structure, tracking systems or transparent panels can be used to allow light to pass through and at the same time generate electricity (0).

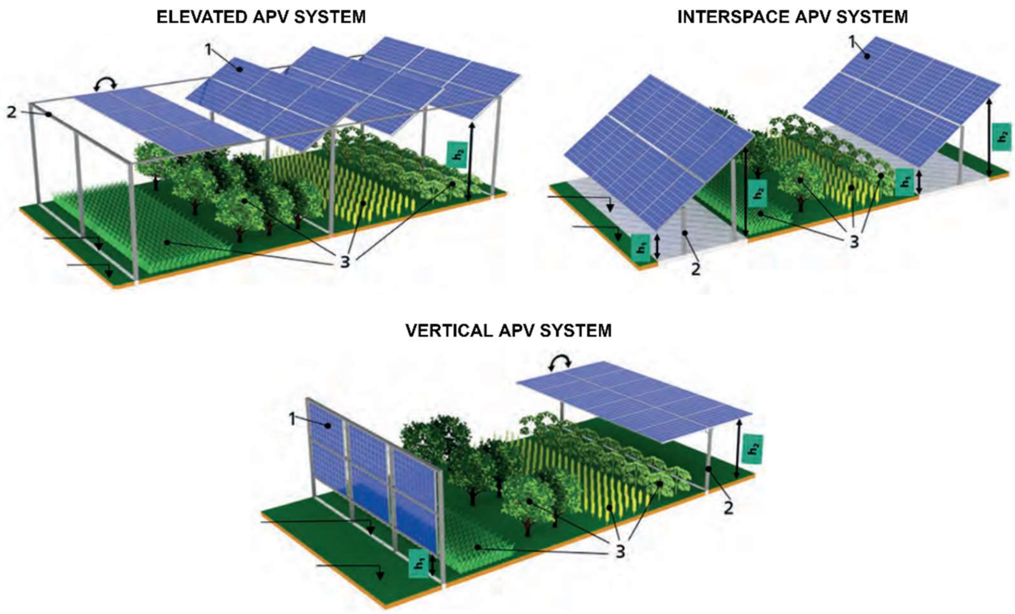

Figure 2: Types of APV systems (0)

4.2 The impact of APV systems on plants and soil

APV systems have become popular as a sustainable solution for producing renewable energy and increasing crop yields. However, it is important to understand their impact on the plants to optimise their use, as shading from PV can reduce crop yields. The main challenge of the technology is therefore the reduced amount of sunlight reaching the plants under APV systems, but this also improves soil moisture and lowers the ambient temperature, which is beneficial during dry periods. The effects of shading vary depending on the type of plant, so the specifics of the individual plants grown in the greenhouses under the PV modules must be taken into account when installing the PV modules.

In Japan (0), where APVs have been used since 2004, these systems have been deployed on 560 hectares of agricultural land. Most of them cover small farms, where vegetables, fruit trees, tea and mushrooms are grown. The density of PV modules varies depending on the crop - from 30% shading for mushrooms and ginger, to lower shading for beans and wheat, which require more sunlight.

A French study (0) looked at the impact of shading on lettuce crops. Summer yields were reduced to 58% under full shading and 81% under half shading, while spring yields were less affected. They found that shaded plants made better use of the available light than those without shading, and different lettuce varieties responded differently - some even performed better in partially shaded areas. The study showed that half shading only slightly affects yields, while full shading significantly reduces yields.

5 SUPPORT SCHEMES

For many years, various support schemes have been implemented at the EU level to promote the construction of different renewable energy sources (RES). In recent years, APVs, which are also RES, have become increasingly popular. They are considered to contribute effectively to the green transition, making them eligible for various operational and support schemes provided by the EU and its member states. In the past, when solar and wind energy were still economically inviable, schemes such as the "feed-in tariff" (FiT), "feed-in premium" (FiP), investment support, and guarantees of origin (GO) were used. With technological advancements, the cost of matured technologies has decreased significantly, making FiT and FiP schemes unsuitable in the current situation. Therefore, the EU is encouraging the implementation of new support schemes such as the Contract for Difference (CfD) and the Power Purchase Agreement (PPA). These support schemes still protect investors against extreme events in the electricity market while reducing the financial burden on individual countries.

5.1 Contract for Difference

The CfD support scheme is determined through a tendering procedure where investors compete against each other by offering the lowest price that still allows them to carry out the project. The lowest offered price is then set and referred to as the strike price. In addition to the strike price, the mechanism also requires a reference price, which is determined based on the market electricity price according to the market price over a given period (hourly, daily, weekly, etc.). The mechanism operates by calculating the differences between the strike price and the reference price over a specific time interval, as shown in Figure 3.

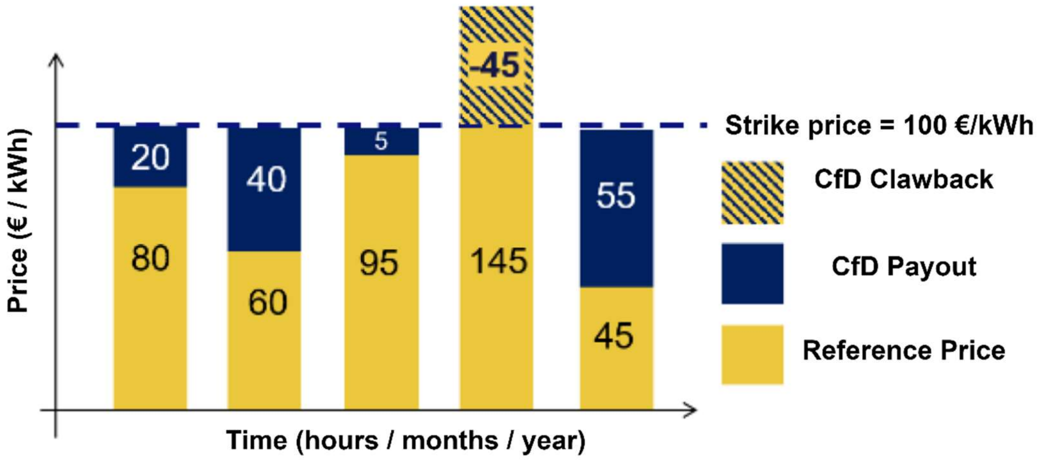

Figure 3: CfD mechanism (0)

If the strike price is above the reference price, the state is obligated to pay the difference to the investor. Conversely, if the reference price is higher than the strike price, the investor pays the difference to the state. The settlement is carried out once a year, summing up the individual differences. The implementation of the CfD mechanism effectively protects the investors and the states against extreme price fluctuations in the electricity market (0).

5.2 Power Purchase Agreement

PPA agreements (0) can be implemented through private or public partnerships. Within private or corporate PPAs, they can be further divided into physical and virtual agreements, with the transfer of electricity taking place either through the public grid or at the site of electricity production. Although PPAs generally have complex structures, they offer benefits to both electricity producers, by providing long-term stability and guaranteed offtake, and to electricity consumers, by securing energy at a price lower than the market rate. In addition to the lower price, in certain countries, consumers also obtain guarantees of origin, which can be an added feature of the PPA scheme, further enhancing its attractiveness.

5.3 Coexistence of CfD and PPA on the market

The key to implementing CfD and PPA mechanisms is their design, which must comply with legislation while incorporating safeguards for both the state and investors (0). In addition to an appropriate design, it is necessary to clearly define the potential coexistence of CfD and PPA mechanisms in the electricity market, as improper design can significantly distort the market. In many countries, the coexistence of PPAs and CfDs is not legally feasible due to the risk of market distortion. For example, an electricity producer could sign a contract with the state (CfD) during periods of low electricity prices or increased risks, while in favourable market conditions, the producer could enter into agreements through the PPA system at a private level. This would result in significant financial gains for the electricity producer, while consumers would pay more, and the state would also incur losses. Currently, Spain is one of the few countries that successfully combines both types of contracts, allowing producers to sell electricity under both systems as long as they meet the minimum agreed electricity production under the CfD system. Essentially, this means that a project owner can trade a guaranteed portion with the state while trading excess production with private entities.

6 CONCLUSION

The article presents the European project ECOLOOP, which explores the potential for a green transition in rural areas through the use of established and new renewable energy technologies. It describes the demonstration locations, technologies, and objectives of the project. Additionally, various APV systems are detailed, which combine electricity production with agriculture and offer solutions for climate change challenges. The shading provided by photovoltaic modules protects plants from heat, reduces water evaporation, and creates a stable microclimate, while also shielding plants from extreme weather events such as hail and heavy rain. This protection can increase crop yields, particularly during hot and dry periods. The dual use of land for agriculture and energy production optimizes space utilization and contributes to emission reductions, which aligns with the EU's sustainability goals. Support schemes serve as incentives for investors in the renewable energy sector. Despite the lower cost of established renewable energy technologies, the EU continues to allow and encourage the use of support schemes, but in a new, revised form. The EU has proposed CfD and PPA as key mechanisms. Both mechanisms have complex structures, and their effectiveness largely depends on the quality of the administrative processes and legal regulations. An interesting aspect of these mechanisms is their potential coexistence in the market. However, careful consideration is needed in the design phase to prevent potential market distortions that could benefit investors disproportionately.

7 ACKNOWLEDGMENT

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