

# European Bioenergy Pathways for the Green Transition in Rural Sectors: Demonstration Activities and Economic Analysis of Novel Support Schemes

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**Abstract** — This paper examines the green transition in agriculture and forestry in response to the European Union’s climate and energy objectives. As these sectors prepare for rapid transformation, the EU-funded project ECOLOOP supports stakeholders by providing tools, knowledge, and business models to facilitate sustainable change. The article presents the Slovenian pilot site, which consists of two locations demonstrating the integration of modular bioenergy technologies and circular practices through a set of targeted Use Cases. Several UCs address system flexibility, creating synergies with the EU-funded STREAM project and enabling coordinated monitoring across initiatives. Among the methodological approaches applied, the Triple-Layer Business Model Canvas is used to assess proposed solutions across economic, environmental, and social dimensions. In addition, the paper investigates novel support schemes for the deployment of renewable energy sources, focusing on Contracts for Difference and Power Purchase Agreements. A detailed economic analysis is conducted based on Slovenian data, evaluating not only the individual performance of CfD and PPA schemes but also their coexistence in two distinct operational scenarios. The results highlight the importance of clearly defined tendering procedures and coherent legislative design to mitigate investor uncertainty. Moreover, they suggest that well-structured hybrid CfD/PPA approaches could enhance the bankability and scalability of RES projects, while cautioning that market distortions and regulatory misalignments must be carefully managed when implementing coexisting mechanisms.

**Keywords** — Contract for Difference, ECOLOOP Project, Economic Analysis, Power Purchase Agreement, Triple-Layer Business Model Canvas

## I. INTRODUCTION

The agriculture and forestry sectors are undergoing increasing pressure to align with the European Union’s ambitious climate and energy objectives, as outlined in the European Green Deal [1] and the "Fit for 55" [2] package. These sectors account for a significant share of greenhouse gas emissions and natural resource use. Yet, they also hold great potential for contributing to the transition toward a low-carbon, circular economy. The challenge lies in enabling this transformation while ensuring economic viability, environmental sustainability, and social acceptance, especially for small and medium-sized stakeholders who often lack access

to the necessary tools, technologies, and investment frameworks.

To support this transition, the EU-funded ECOLOOP project [3] aims to demonstrate innovative bioenergy solutions that are modular, scalable, and tailored to local conditions. ECOLOOP equips farmers and foresters with replicable models for clean energy generation and resource optimisation by integrating circular bioeconomy principles and leveraging underutilised biomass and organic waste streams. The project also emphasises operational flexibility and market participation as key enablers of system resilience and economic feasibility.

This paper focuses on the Slovenian pilot site as part of the ECOLOOP project, which includes two demonstration locations: Biomass Centre Nazarje, a large-scale woody biomass facility, and Infrastructure Centre (IC) Jablje, a modular micro biogas plant managed by the Agricultural Institute of Slovenia. Across both locations, six Use Cases (UCs) are being implemented to address topics such as energy system optimisation, ancillary services (AS), modular technology development, biochar valorisation, biomethane production, and business model (BM) redesign. All the UCs are briefly presented in the paper. In addition, this paper further explores the Triple-Layer Business Model Canvas (TLBMC) applied within the ECOLOOP project to extend conventional cost-benefit analysis beyond the established boundaries by incorporating environmental and social criteria, thus supporting more comprehensive sustainability assessment.

Recent research has increasingly focused on long-term contracting mechanisms to support renewable energy deployment, with particular attention to Contracts for Difference (CfDs) and Power Purchase Agreements (PPAs). A prominent direction in the literature is the development of hybrid contracting models aimed at reducing revenue volatility while preserving efficient market signals. [4] critically examine the limitations of conventional CfDs, showing how direct coupling of payments to physical output can distort dispatch incentives and investor behavior. Their proposed financial CfD design addresses this by decoupling support from generation, though it remains theoretical and lacks techno-economic validation in real-world applications. In contrast, [5] focus on empirical hedging strategies for PPAs using short- and medium-term

electricity futures, employing stochastic modeling to quantify hedge effectiveness under price and volume risk. While this provides valuable market-based tools, it does not consider how PPA design interacts with other support mechanisms like CfDs. [6] offer a portfolio optimization framework to explore revenue stability from mixed CfD-merchant exposure structures in wind and solar assets, advancing understanding of hybridization, yet again limited to non-dispatchable technologies and absent any cross-mechanism coexistence modeling.

Together, these studies reflect the state-of-the-art in risk-mitigation and investment support for variable renewables. However, they reveal several unresolved challenges: limited application to firm, dispatchable RES such as bioenergy, a lack of integrated modeling of CfD and PPA coexistence, and insufficient techno-economic analysis grounded in real project data. Our study directly addresses these shortcomings by developing a techno-economic assessment of a biomass power plant under distinct and coexisting CfD and PPA configurations. Using national-level data from Slovenia, we analyse how each mechanism affects investment attractiveness, price stability, and system efficiency under conditions such as surplus generation and negative prices. This approach not only fills a clear methodological and empirical gap but also supports the broader transition toward diversified, resilient contracting strategies applicable to dispatchable renewable energy sources.

Overall, the latter aims to inform policy development and project design by providing evidence-based insights into the viability and design of hybrid support mechanisms, while demonstrating how decentralised bioenergy systems can contribute meaningfully to the EU's green transition goals.

The paper is structured as follows. First, the EU-funded ECOLOOP project is introduced, with a focus on the Slovenian pilot site, the project's UCs, and the innovative TLBMC. This is followed by an economic analysis of innovative support schemes available to RES investors across the EU, including a detailed comparison and discussion of CfDs and PPAs. The paper concludes with a summary of the key findings and an outline of planned future work.

## II. ECOLOOP

The ECOLOOP project, funded by the Horizon Europe programme, brings together 14 partners from four EU countries, as shown in Figure 1. Its goal is to provide farmers and foresters with the tools, knowledge, and BMs needed to manage land, forests, but also waste more efficiently.

The ECOLOOP project brings forward innovative solutions to support the use of decentralised RES in rural areas, with a focus on the efficient integration of solar and geothermal energy alongside various forms of bioenergy, such as biogas and biofuels. A key objective is to develop new and enhance existing processes – such as modular slow pyrolysis – that improve the efficiency of biogas production from agricultural and forestry by-products or waste, while enabling the combined use of geothermal and solar energy. The project's overarching goal is to optimise bioenergy production processes and develop bio-based products from agricultural and forestry residues, helping to reduce reliance on fossil fuels and lower greenhouse gas emissions. It also includes the development and application of

advanced methods for digestate utilisation as organic fertiliser, as well as protocols and strategies for carbon capture and sequestration to further reduce emissions. ECOLOOP promotes circular and sustainable practices in agriculture and forestry by applying cutting-edge technologies and innovative BMs. Enhancing biodiversity, soil health, and groundwater quality are also central to the project's vision. To support regional development in rural areas, ECOLOOP is creating a comprehensive framework that integrates policy, technology, and economic tools. This includes new strategies and financial incentives designed to encourage even small-scale farmers and foresters to adopt sustainable, innovative technologies.



Figure 1: Project ECOLOOP description.

ECOLOOP's innovative solutions will be tested through four large-scale demonstration pilots in Spain, Slovenia, Estonia, and Bulgaria. These pilots will span entire value chains and include a variety of crops, plantations, and tree species across the agroforestry and forestry sectors. They will also integrate multiple energy sources and technologies while addressing diverse climatic, geographical, and socio-economic contexts.

## III. SLOVENIAN PILOT SITE

The Slovenian pilot consists of two locations. The first is the Biomass Centre Nazarje, situated in an industrial zone and dedicated to converting wood waste and less valuable wood into woody biomass for power, heat, and fuel production. The site operates a fully automated system that manages the preparation, transport, and feeding of materials into wood gasifiers. Using pyrolysis technology, it combines a wood gasifier with a Combined Heat and Power (CHP) system to produce both electricity and heat. The facility generates wood gas from chips and pellets to power 12 modular CHP units, delivering a total capacity of 550 kW<sub>e</sub> and 1,200 kW<sub>th</sub>. It also operates two biomass boilers with capacities of 1.5 MW<sub>th</sub> and 4.0 MW<sub>th</sub>. Each

year, the centre produces approximately 150,000 nm<sup>3</sup> of dried wood chips, 15,000 tons of pellets, and 6.5 GWh of electricity.

Planned upgrades include new CHP units (300 kW<sub>e</sub>/600 kW<sub>th</sub> and 500 kW<sub>e</sub>/900 kW<sub>th</sub>), a 300 kW electric vehicle (EV) charging point, two photovoltaics (PV) power plants (1.0 MW and 0.7 MW), and a battery energy storage system (BESS) (2.5 MW/5.0 MWh). As part of the ECOLOOP project, optimal operational schedules for each energy asset will be developed to maximise market opportunities, enhance efficiency and supply security, and provide AS for the grid operator to support grid stability.

Additionally, the centre will develop a modular woody biomass power plant prototype tailored to small-scale users such as sawmills or farms. Flexibility in slow pyrolysis processes will also be tested by exploring how operating temperatures affect biochar output, which could serve as a biofertilizer.

The second pilot site is IC Jablje, managed by the Agricultural Institute of Slovenia, and hosts a modular micro biomass plant. This facility includes an anaerobic digester, a biogas holder, and a 7 kW<sub>e</sub>/16 kW<sub>th</sub> cogeneration unit. Planned improvements include biomethane production, storage, and a refuelling station for biomethane-powered tractors. In parallel, the quality of biochar produced at the Biomass Centre’s pyrolysis CHP system will be analysed for its potential agricultural applications.

#### A. Use Cases

The UCs of the Slovenian pilot site are primarily focused on the utilisation of two groups of assets, which are in the respective pilot locations. The first group focuses on the successful demonstration of CHP operation, while the second part is focused on biomethane capture.

**UC SI.01 – Optimizing Operations and Strengthening Supply Security at Biomass Centre Nazarje** focuses on improving the energy system at Biomass Centre Nazarje by integrating existing and planned infrastructure – CHP units, biomass boilers, EV chargers, solar PV, and BESS. The aim is to boost market participation, operational efficiency, and supply reliability, while also assessing the potential to deliver surplus heat to nearby industrial users, providing environmental and social benefits.

**UC SI.02 – Leveraging Flexibility for Grid Support at Biomass Centre Nazarje** explores how the centre’s energy assets can support grid stability and generate passive revenue through ancillary services. Using an aggregation platform and historical data, it targets strategic participation in flexibility markets to enable better renewable integration.

**UC SI.03 – Development of a Modular Biomass Slow Pyrolysis System** develops a containerised, modular CHP unit based on slow pyrolysis of woody biomass. Tailored for small-scale users like sawmills or farms, the system will demonstrate standardisation, scalability, and adaptability to local energy needs.

**UC SI.04 – Maximising Biochar Utilisation** aims to optimise biochar production during CHP operations by studying how pyrolysis temperature affects energy output and byproduct

yield. The biochar’s quality will be assessed for agricultural use, contributing to the economic viability of CHP systems.

**UC SI.05 – Utilising Biomethane from Biogas for Agricultural Machinery** at IC Jablje, advances a two-phase process to upgrade biogas from organic waste into high-quality biomethane for fueling farm machinery. It also produces organic fertiliser, promoting circular economy practices at the Agricultural Institute of Slovenia’s micro biogas plant.

**UC SI.06 – Redesigning Subsidies and Business Models for Biogas Solutions** proposes new business models and subsidy schemes to support biogas and biomethane adoption in agriculture. It aims to reduce emissions, boost energy self-sufficiency, and drive rural development through scalable, policy-aligned financial innovations.

The know-how and efficient market integration of the flexibility assets of the UC1 and UC2 are also outcome of previous work on industrial flexibility provision on markets, through the aggregator’s platform, which was previously tested, adapted and evaluated in another EU funded project named STREAM [7], which is focused on utilising the flexibility potential of the commercial sector.

#### B. Triple Layer Business Models

To assess the business models (BMs) of the pilot sites, the Triple Layer Business Model Canvas (TLBMC), shown in Figure 2, was used. This expanded version of the traditional BM Canvas includes environmental and social layers, enabling a comprehensive evaluation of each pilot’s economic viability, sustainability, and social impact. It is especially suited for initiatives involving renewable energy, circular economy, and community innovation. The environmental layer focuses on resource use, emissions, and circularity, while the social layer considers stakeholder engagement, equity, and societal benefits. Together, the three layers offer a structured and holistic framework to align technical solutions with sustainability and policy objectives.

Economic layer				
Stakeholders	Activities	Customer relationship	Resources	Channels
Costs	Revenues		Target customer segments	
Environmental layer				
Supplies and outsourcing	Production	Functional value	Use phase	Environmental Benefits
	Materials	Distribution	End of Life	
Social layer				
Local communities		Governance	Scale of impact	End user impact
Employees	Social value	Societal Culture		Social Benefits

Figure 2: Triple Layer Business Model Canvas.

#### IV. SUPPORT SCHEMES AND MARKET INTEGRATION

At the EU level, numerous support schemes and mechanisms have been established over the years to accelerate the

deployment of RES [8]. In May 2024, the European electricity market design reform was introduced through Regulation (EU) 2024/1747 [9]. The adoption of Contracts for Difference (CfD) and Power Purchase Agreements (PPAs) has been acknowledged as a powerful incentive to promote the further development and deployment of various RES technologies, including bioenergy and biomass power generation.

### A. Methodology

#### 1) Biomass power plant

In order to conduct a representative economic analysis of a biomass power plant situated in Slovenia, the total annual Slovenian yearly biomass power plant generation, on an hourly basis, was obtained from [10] and the installed capacity from [11]. These national-level datasets were used in place of pilot site data due to the unavailability of high-resolution operational data at the initial stages of the project. The use of aggregated, country-level data provides a consistent and complete basis for scalable analysis. For this purpose, the data was normalized to reflect the energy production of a biomass plant with a nominal capacity of 1 MW operating under average national conditions. The resulting generation profile is shown in Figure 3. It is worth noting the drop in production during the last quarter of the year. This behaviour realistically reflects the operation of the plant, as such a decline could represent scheduled maintenance activities.

The economic analysis, including data processing, normalization, and scaling, was performed using Python, leveraging its capabilities for handling time-series data and computational modeling.

#### 2) Contract for Difference

CfDs are already well-established financial instruments with diverse applications across various sectors. In recent years, they have gained significant popularity in the RES sector as a mechanism to stabilise revenues and mitigate risks for investors. CfDs are based on the difference between a fixed strike price and a reference price. The strike price is typically determined through tendering procedures by the bidders, while the reference price is pre-set for specific time periods (hours, days, weeks, months). The core of the mechanism involves an annual net payment exchanged between two parties. The process works as follows: if the strike price exceeds the reference price, producers receive payments. Conversely, if the reference price exceeds the strike price, producers must make payments to the counterparty, typically a government or corresponding national entity [12].

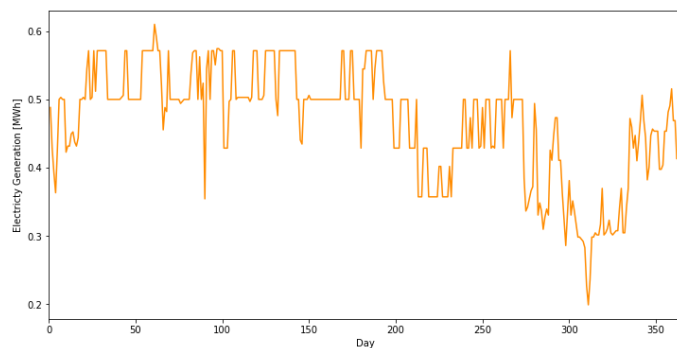


Figure 3: Yearly production profile of analysed biomass power plant.

Given the inherent complexity of CfDs, a well-defined methodology is crucial for conducting robust economic analyses and facilitating effective market implementation. The presented analysis applies to a biomass power generation system, utilising multiple derivations to obtain comprehensive insights.

Strike prices were determined based on the average Day-Ahead Market (DAM) price in Slovenia for 2023 [13], set at 105 EUR/MWh. The analysis explores three strike price scenarios: 85 EUR, 105 EUR, and 120 EUR/MWh. Reference prices cover various intervals, including average hourly, daily, weekly, monthly, and yearly periods, and are also based on the DAM market. The study incorporates CfDs with band gaps (BGs), designed to introduce flexibility by disregarding minor discrepancies between the strike and reference prices. This approach minimises the number of insignificant payments, which have negligible effects on annual net payments. For this analysis, the contract duration was set to 15 years, although the economic evaluations are conducted based on a single annual settlement.

#### 3) Power Purchase Agreement

PPAs are designed to facilitate the sale or purchase of electricity outside the wholesale electricity market. These contracts are entered into by two or more entities, outlining terms such as duration, quantity, pricing methods, and invoicing procedures [14].

Due to the wide range of PPA structures, implementing and executing the mechanism can be complex. For this study, a simplified scenario with two entities is considered. The electricity producer owns the biomass power plant, while the consumer is an energy-intensive company that operates continuously. This implies that all electricity produced by the producer is fully consumed by the company, which also fully bears the reconciliation costs.

Given the low liquidity of Slovenian power futures, the prices were sourced from the Hungarian derivative exchange HUDEX [15], considered the most suitable approximation as Quarter Futures for 2024 Q2, Q3, Q4, and 2025 Q1. These prices were then adjusted by factors of 2 %, 7 %, and 12 % to ensure profitability for both stakeholders, the producer and the consumer. A price spread of 10 % was applied to enable a sensitivity analysis. Also in this case, the contract duration was set to 15 years, with economic analyses conducted on an annual basis.

#### 4) Coexistence of Contract for Difference and Power Purchase Agreement on the market

To ensure the transparent and equitable coexistence of CfD and PPA mechanisms in the market, thorough analysis and legislative adaptations are required. Poorly designed mechanisms or legislation can lead to market distortions, such as incorrect production signals (e.g., producing when prices are below marginal costs or ceasing production when prices are above marginal costs) or non-cost-based bidding that affects price formation [12], [16]. The study presented in this paper examined two coexisting mechanisms:

- Switch off CfD/on PPA when the market prices are negative.

- Predefined minimum mandatory production (450 kWh) on the hourly basis under the CfD scheme.

## B. Results

### 1) Contract for Difference

The analysed scenario yields an annual production of 4,092 MWh. Under the CfD scheme, the producer sells electricity on the market, generating a yearly profit of 430,460 EUR. The two-way CfD mechanism supplements this income based on the strike price and reference period. A sufficiently high strike price results in additional earnings, while a lower strike price may trigger clawback payments, reducing profits. In general, higher strike prices increase revenue, whereas longer reference periods reduce both gains and losses. As shown in Table I below, differences between reference periods are minimal, primarily due to the stable generation profile of biomass power plants.

### 2) Power Purchase Agreement

As an alternative to the CfD, the PPA mechanism was also evaluated. Under a PPA, electricity is sold directly to a designated buyer rather than on the wholesale market. For prosumers, the main advantage is reduced risk, as PPAs protect against short-term market price fluctuations. Profitability results are presented in Table I. Compared to the CfD scenario with the highest strike price and an hourly reference period, the PPA delivers similar financial outcomes. Considering the structure of both mechanisms, including risk exposure, cost implications, and market dependence, the PPA appears to be the more favourable option for stakeholders.

Table I: Results of PPA and CfD mechanism.

Adjustment factor (PPA)	Revenue [EUR/Year]				
+ 2 %	438,290				
+ 7 %	459,775				
+ 12 %	481,260				
Target Price (CfD)	Revenue [EUR/Year]				
	Hour	Day	Week	Month	Year
85 EUR/MWh	-74,385	-73,165	-73,263	-68,896	-61,738
105 EUR/MWh	-1,077	-350	-5,307	-5,934	0
120 EUR/MWh	53,004	50,256	46,042	45,006	39,547

### 3) Coexistence of Contract for Difference and Power Purchase Agreement on the market

A detailed analysis was performed to evaluate the simultaneous integration of the PPA (+ 7 %) and two-way CfD mechanisms. Two different scenarios were examined to assess their feasibility and economic impact.

#### a) Switching off CfD and switching on PPA when market prices are negative

- This mechanism relies on continuous monitoring of 15-minute electricity price fluctuations.
- Due to the rarity of negative electricity prices (only occurring in hourly and daily referencing period), this approach proved inefficient for the PPA stakeholders – rarely CfD mechanism is turned off.

- Market revenues equal to around 430,000 EUR (fluctuating slightly with referencing period change).
- However, with increasing RES penetration, negative prices are expected to become more frequent, potentially making this scenario more viable in the future.

#### b) Predefined minimum mandatory production under the CfD scheme

- A threshold of 450 kWh was established, meaning electricity generated beyond this level was sold through the PPA mechanism, while the base production was traded under the CfD scheme and sold to the market.
- The revenue from electricity sold on the market was equal to 386,242 EUR, which is lower than in previous scenario.
- Figure 5 shows that the predefined production boundary was frequently exceeded in the first 10 months of the year. In the last two months of the year, the production was in general, lower and therefore the boundary was crossed more infrequently. Table II shows the revenues of the PPA and CfD mechanisms.

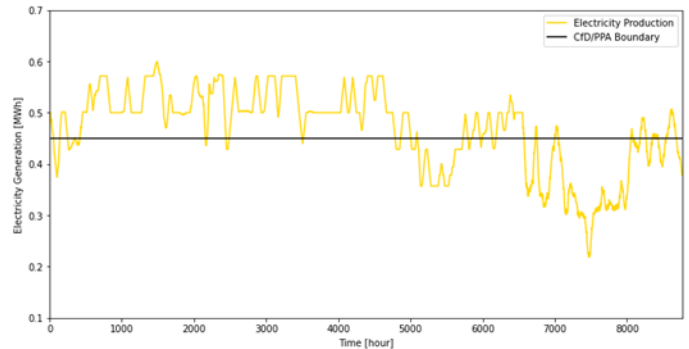


Figure 4: Yearly profile of electricity production and CfD/PPA boundary.

- This approach improves transparency, reduces a state's financial burdens and prevents market distortions.

Table II: Results of PPA and CfD mechanism for the scenario of Predefined minimum mandatory production under the CfD scheme.

Adjustment factor (PPA)	Revenue [EUR/Year]				
+ 2 %	48,223				
+ 7 %	50,587				
+ 12 %	52,921				
Target Price (CfD)	Revenue [EUR/Year]				
	Hour	Day	Week	Month	Year
85 EUR/MWh	-65,928	-64,765	-64,301	-60,995	-55,550
105 EUR/MWh	-42	-734	-3,188	-4,669	0
120 EUR/MWh	48,635	46,250	42,959	41,329	35,583

The analysis shows that the economic viability of CfD, PPA, and their coexistence is highly context dependent and influenced by contract parameters, especially the strike price in CfD

schemes. When aimed at reducing investor risk, the strike price should reflect average generation costs and market volatility. If intended to stimulate new investment, it may need to be more favourable. For bioenergy projects, which offer stable and dispatchable output, PPAs are particularly suitable, providing predictable revenues aligned with market conditions and supporting long-term relationships between producers and off-takers. Promoting PPAs in this sector could diversify renewable energy support and reduce reliance on variable sources such as wind and solar.

Although coexistence schemes may not always deliver the highest economic returns, especially under minimum production thresholds or during negative pricing, their value lies in operational flexibility. These models allow assets to adjust output based on real-time price signals or system needs, offering a more adaptable framework than single-mechanism approaches. This hybrid model supports both investment security and integration with broader system objectives. It represents a promising pathway for efficient deployment of dispatchable renewables in complex electricity markets. The study focuses on economic aspects only, with regulatory and systemic considerations beyond its scope.

## V. CONCLUSION AND FUTURE WORK

The paper describes the European project ECOLOOP and its main scope, aiming to empower the rural sector. The integration of RES technologies into advanced farming and forestry practices enables the agricultural sector to play an active role in the green energy transition process and shift towards a sustainable future. Part of the project activities are demonstration of advanced CHP integration and operation, and development of innovative BMs for further replication of good practices and lessons learned.

The paper presents novel support schemes to accelerate efficient RES integration. A detailed economic analysis of bioenergy technologies compares CfD and PPA schemes, showing only minor economic differences in the study area. Two-way CfDs suit bioenergy well, while PPAs offer a lower-risk alternative and should be promoted when possible. The coexistence of both can enable faster, lower-risk RES growth. Of the two, the predefined minimum mandatory production under CfD stands out as the most transparent, economically viable, and technically feasible option.

In the future, innovative RES technologies, such as hydrogen technologies, should also be analysed. The Carbon Contract for Difference (CCfD) should be thoroughly analysed as a support scheme for facilitating the market integration of emerging RES technologies.

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