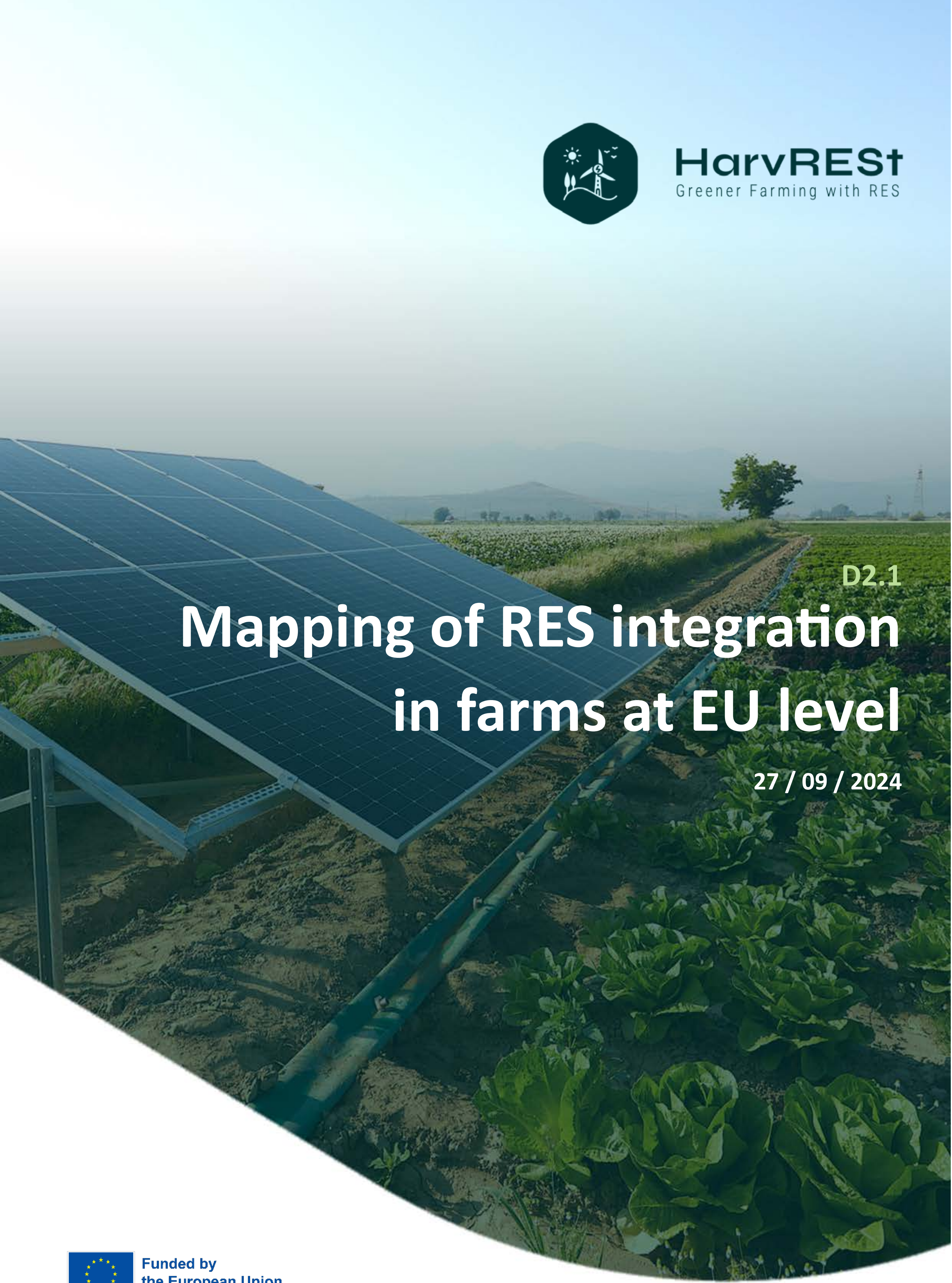

HarvRESt
Greener Farming with RES

D2.1

Mapping of RES integration in farms at EU level

27 / 09 / 2024

Funded by the European Union

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TABLE OF CONTENTS

ABBREVIATIONS

AVPP	Agricultural Virtual Power Plant
BG	Biogas
BMS	Building Management System
CAP	Common Agricultural Policy
CATI	Computer-Assisted Telephone Interviewing
CHP	Combined Heat and Power
DSS	Decision Support System
EDA	Exploratory Data Analysis
EPA	Effective Projected Area
ESG	Environmental, Social and Governance
ETS	Emissions Trading System
EU	European Union
FAO	Food and Agriculture Organisation
FIT	Feed-in Tariffs
FIP	Feed-in Premiums
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
GSE	Gestore Servizi Energetici (Italian)
ICT	Information and Communication Technologies
IDAE	Instituto para la Diversificación y Ahorro de la Energía (Spanish)
IFES	Integrated Food-Energy Systems
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
IVs	Independent Variables
KER	Key Exploitable Result
KPI	Key Performance Indicator
MHP	Micro Hydropower
MWPCI	Megawatt Power Capacity Installed
NECP	National Energy and Climate Plans
PAT	Pump as Turbine
PEPAC	Strategic Plan for Common Agricultural Policy (Plan Estrategico para la Politica Agraria Común in Spanish)
PEU	Perceived Ease Of Use

PNIEC	Piano Nazionale Integrato Energia e Clima (Italian)
PU	Perceived Usefulness
PV	Photovoltaics
PVT	Photovoltaic Thermal
RD	Royal Decree
RECs	Renewable Energy Communities
REM	Remuneration of Renewable Energy Resources
RES	Renewable Energy Sources
RH	Relative Humidity
RQs	Research Questions
R&D	Research and Development
SA	Specific Area
SFT	Sustainable Farming Technology
TAM	Technology Acceptance Model
UAA	Utilised Agricultural Area
UC	Use Case
UPNA	Public University of Navarre
UNEF	Unión Española de Energía Fotovoltaica (Spanish)
VOCs	Volatile Organic Compounds

1. EXECUTIVE SUMMARY

This report, Deliverable 2.1 of the HarvREStproject, provides an analysis of the integration of Renewable Energy Sources (RES) into agricultural practices. For a more detailed and reader-friendly summary of this report, please refer to Annex 6 Detailed Summary. The deliverable covers three essential tasks: **Task 2.1**, which maps best practices for farm decarbonization; **Task 2.2**, which assesses stakeholder needs and regulatory frameworks for RES adoption in Europe; and **Task 2.3**, which characterizes specific use cases in Italy, Spain, Denmark, and Norway.

Task 2.1 identifies effective practices and initiatives aimed at reducing carbon emissions in agriculture. A key insight is that **strategic placement** of RES infrastructure, such as wind turbines and solar panels, can help balance energy production with biodiversity conservation. However, careful planning is essential to avoid negative impacts on ecosystems and agricultural productivity. Technologies such as **biomass** and **agrivoltaics** (solar panels used alongside crops) are highlighted for their potential to reduce **greenhouse gas emissions** and improve energy efficiency. However, changes in **land use** related to RES installations can lead to biodiversity loss if not properly managed. Practices such as **agroforestry** and using marginal lands for energy installations are recommended to minimize such impacts. While Task 2.1 demonstrates the potential for RES to contribute to more **sustainable farming**, there are challenges in balancing **climate adaptation** with **food security**. The report stresses that **policy support** and **innovative financing mechanisms** are crucial for making these technologies accessible to farmers. A **holistic approach**, considering environmental, social, and economic factors, is necessary for successful RES integration.

Task 2.2 examines the needs of local stakeholders and the regulatory frameworks supporting RES integration in four countries: Italy, Spain, Denmark, and Norway. A **multi-method approach** was employed, including surveys, interviews, and desk research. The findings show that **stakeholder engagement** is critical for the successful adoption of RES. While farmers generally express openness to integrating renewable energy, **socio-economic factors** such as **farm size**, **education**, and **financial resources** significantly affect adoption rates. In some cases, **legal uncertainties** and **policy barriers**—including zoning restrictions and inconsistent governmental support—are major obstacles. **Policy alignment** at both national and EU levels is crucial to foster the widespread adoption of RES. Financial incentives such as **feed-in tariffs** and **tax reductions**, alongside clear legal frameworks, help mitigate the financial risks of renewable energy projects. Furthermore, **social acceptability** is vital; early engagement with local communities can address concerns related to landscape changes and wildlife impacts, increasing the likelihood of successful RES adoption.

Task 2.3 focuses on specific **HarvREStuse cases** in Italy, Spain, Denmark, and Norway, representing different farm types, climates, and RES technologies. These use cases explore practical applications of RES tailored to local conditions. For instance, the **Italian** use case targets **agro-industrial farms** and decarbonization along the agri-food value chain. In **Spain**, **agrivoltaics** is being experimented with in vineyards, its **impact on crops** is being studied, and **efficient energy management systems** are being tested to help reduce the carbon footprint. Furthermore, a **biorefinery** model for biogas production from **agro-residues** is being studied, addressing the nutrient potential of digestate. **Denmark's** focus is on integrating **biogas** production into farms to create circular energy systems, while in **Norway**, smart energy systems are being developed to manage renewable energy storage and distribution effectively. Each use case highlights both the **potential of RES** to transform agriculture and the challenges involved, such as **financial costs**, **infrastructure development**, and **technical expertise**. The **multi-actor approach** employed—collaborating with farmers, industry, and policymakers—ensures that the solutions developed are scalable, practical, and tailored to the diverse needs of stakeholders.

In conclusion, Deliverable 2.1 emphasizes that the successful integration of RES into agriculture requires a combination of **technological innovation**, **policy support**, and **active stakeholder engagement**. While opportunities for reducing emissions and enhancing farm sustainability are significant, challenges such as **regulatory hurdles**, **financial constraints**, and **land-use conflicts** must be overcome. To promote broader adoption of RES, the HarvRESt project recommends engaging stakeholders from the beginning, providing **education and training** for farmers, and developing policy frameworks that encourage investment in renewable energy. By implementing these approaches, farms can decarbonize their operations while contributing to rural development and energy security across Europe.

2. INTRODUCTION

The integration of Renewable Energy Sources (RES) into agricultural practices represents a transformative approach to advancing sustainability in the farming sector. In an era defined by climate change, resource depletion, and the biodiversity crisis, the HarvRESt project seeks to demonstrate how RES integration in farms can mitigate environmental impacts while improving energy security and profitability at the farm level. This Deliverable 2.1 synthesizes findings from three tasks of the project and offers a more systemic view of RES integration in farms. It highlights not only best practices and the needs of farmers but also focuses on technological solutions, stakeholder engagement, and the impacts on local ecosystems and economies among other things.

This Deliverable 2.1 is structured around three tasks, each contributing to the broader objective of advancing RES integration in agriculture:

1. **Task 2.1:** Focuses on identifying best practices for RES integration at the farm level, with a particular emphasis on social engagement, business models, and innovative farming techniques. The task aims to bridge knowledge gaps, addressing the concerns of farmers who are traditionally hesitant to adopt new technologies. A thorough literature review and analysis of EU project databases were employed to highlight effective strategies and practices for promoting renewable energy use on farms.
2. **Task 2.2:** Investigates the framework conditions and stakeholder needs related to RES integration within specific use cases (UCs) in Italy, Spain, Denmark, and Norway and at the EU level. Through targeted desk research, interviews, and a survey, this task examines the socio-economic, political, and legal barriers to renewable energy integration in farms.
3. **Task 2.3:** Characterizes the specific needs and energy demands of each Use Case in the HarvRESt project, offering a multi-actor perspective on RES implementation. This task outlines the different RES technologies being deployed in the Use Cases, from biogas production to agrivoltaics, and evaluates the challenges and opportunities associated with their integration into diverse agricultural systems.

Each of these tasks' sheds light on various aspects of RES integration in agriculture, emphasizing the need for a systemic approach that considers environmental, economic, and social dimensions. The success of RES integration at the farm level depends not only on technological advancements but also on the alignment of policies, farmer engagement, and the adaptability of farming practices.

Moreover, the integration of RES into farms occurs at various levels, encompassing a range of technologies and operational changes. While some farms may only adopt small-scale renewable systems, others embrace comprehensive shifts in their management practices, energy storage capabilities, and production processes.

Despite the varying levels of RES integration, biomass energy production and agrivoltaics stand out as two of the most advanced technologies in the agricultural context. Both offer substantial benefits for farms, combining energy production with agricultural output. Biomass production provides energy while managing waste and supporting nutrient cycles, whereas agrivoltaics allows for dual land use, with solar panels and crops sharing the same space.

The HarvRESt project serves as a hub for knowledge exchange and innovation in RES integration, leveraging the experience of different European regions and use cases. By bringing together diverse stakeholders—farmers, local authorities, energy communities, and industry partners—the project fosters collaboration and drives the adoption of renewable energy solutions tailored to local needs. The use cases illustrate how RES technologies can be adapted to different agricultural settings, from biogas in Denmark to agrivoltaics in Spain, offering pathways to decarbonizing agriculture and enhancing food security.

This report also addresses the broader challenges of RES integration, including the complex interplay between energy infrastructure, biodiversity, and land use. While RES integration can reduce greenhouse gas emissions and increase energy independence, it must be managed carefully to avoid negative impacts on ecosystems. The strategic placement of RES infrastructure, such as wind turbines or solar panels, can mitigate potential trade-offs and even contribute to biodiversity preservation.

3. MAPPING OF BEST PRACTICES AND EXISTING INITIATIVES ON FARM DECARBONIZATION

This section of the report (Task 2.1) aims to explore best practices in RES integration, focusing on different sources of renewable energy but also on cross-cutting recommendations and a more systemic approach to RES integration.

The methodology used to produce this section of the report includes a literature review encompassing both scientific and grey literature, as well as an analysis of relevant EU project databases such as CORDIS, the EIP-Agri Project Database, and the AgroFossilFree platform. By synthesizing success stories and best practices from publicly available information, this report highlights key pillars of effective RES integration: applications and ideas related to **social engagement and innovative business models**, **agricultural and environmental trade-offs**, and the **deployment of RES alongside smart technologies**.

3.1 Objectives and state of play for RES integration in farms

The integration of RES at the farm level represents a transformative approach to sustainable agriculture, addressing both environmental and economic challenges. As agriculture increasingly faces pressures from climate change, biodiversity crisis and resource depletion, leveraging RES offers opportunities for enhanced energy independence and reduced greenhouse gas emissions.

Energy is consumed directly by agriculture and forestry with the use of machinery (e.g. cultivation of fields with tractors) and the heating of livestock stables and greenhouses. In 2021, agriculture and forestry accounted for a 3.0 % share of the total direct energy consumption in the EU [1].

The use of RES as an alternative to fossil fuels on farms can contribute to the reduction of this impact. However, RES are only one part of the solution to address the broader climate impact of agriculture. Beyond energy-related emissions, farm activities generate three types of GHG emissions: carbon dioxide (CO_2) from poor soil management and land use changes; methane (CH4) mainly from ruminant digestion and poor manure management; and nitrous oxide (N2O) from excess fertilisation of agricultural soils [2]. RES integration must therefore be part of a wider climate change mitigation strategy in order to reduce the whole range of emissions generated on farms and store more carbon in soils. Moreover, indirect uses of energy in the agrifood system, such as for the production of agrochemicals, should also be addressed.

The interplay between climate change, energy, environment, biodiversity, food security, food safety, and agricultural production is complex and multifaceted, marked by both trade-offs and synergies. Climate change impacts agricultural productivity. For instance, shifting weather patterns can reduce crop yields, making it essential to adopt drought-resistant crops and diversified farming systems [3]. Renewable energy integration at the farm level, such as solar panels and biogas production, can reduce greenhouse gas emissions and enhance environmental sustainability. However, the expansion of energy infrastructure must be managed to avoid biodiversity loss, ecosystem disruption, as well as loss of agricultural land and productivity. As Ortiz et al. [4] showed in their analysis of agriculture, climate, biodiversity and international trade nexus, biodiversity needs to be considered more when analysing the food system (Figure 1). For example, careful placement of wind turbines in agricultural land is necessary to protect bird populations [5].

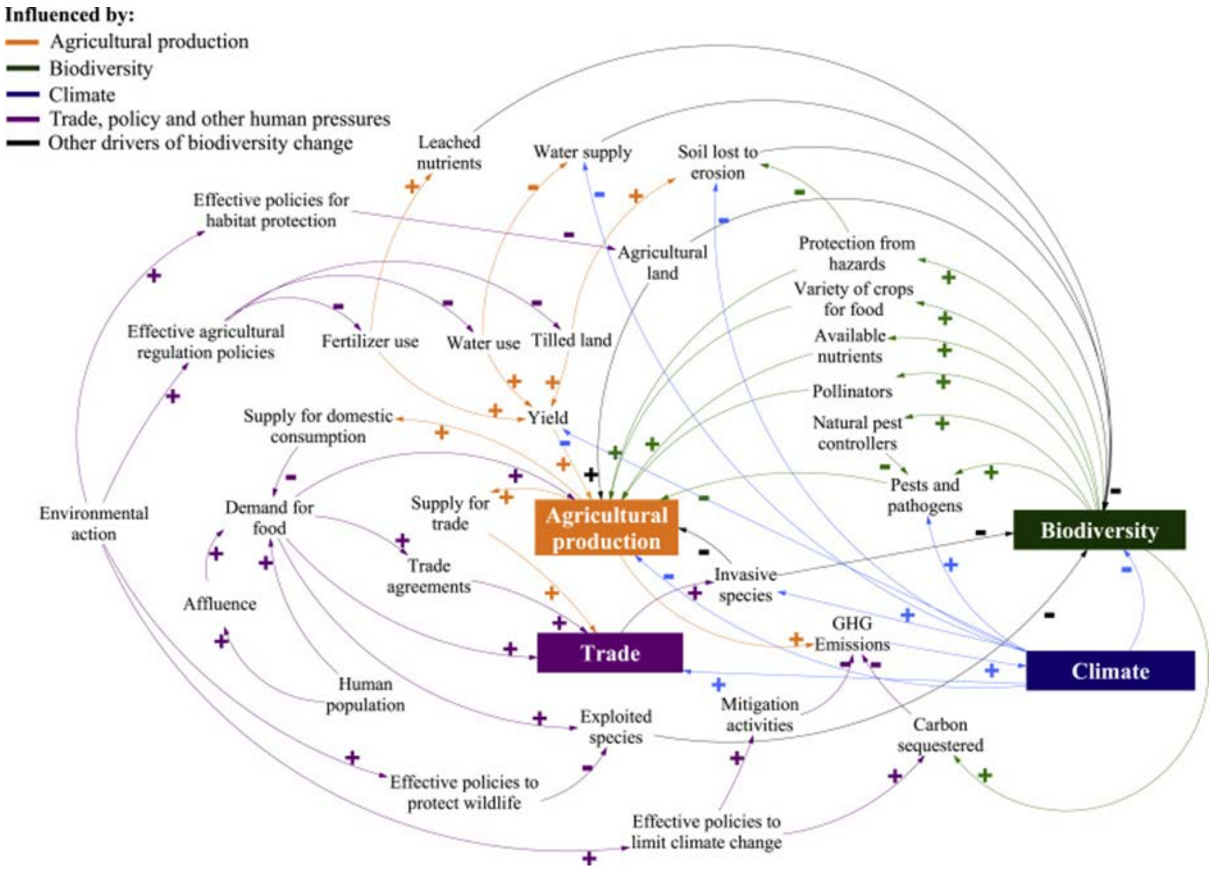

Figure 1. The climate-agriculture-biodiversity-trade nexus mapped by Ortiz et al. (2021) [4]

Furthermore, land use changes play a significant role in this nexus. Converting natural habitats into agricultural land can lead to significant biodiversity loss [6]. The introduction of RES in agricultural land also can lead to higher prices on the land itself and thus land-use change disfavouring agriculture production [7]. Implementing practices like agroforestry and maintaining buffer zones around natural habitats can mitigate these impacts while supporting biodiversity [8]. Additionally, synergies can arise when sustainable land management practices promote soil health, efficient water management, and renewable energy such as Agri-PV [9].

Moreover, at the farm level, RES adoption can optimize energy use, reduce costs, and enhance energy security [10]. Regarding the local communities, renewable energy systems on farms can stimulate economic growth and new business opportunities [11]. RES can also play a pivotal role in addressing issues with food availability and food security- stabilized energy prices for farmers can also help stabilize agricultural production [12,13]. Lastly, RES can even boost biodiversity if they are well designed, such in the case of solar panels [14].

To achieve optimal integration of RES at the farm level, it is also essential to consider broader aspects beyond the immediate farm operations. Stakeholder engagement, including farmers, local communities, policymakers, and industry partners, is crucial for developing effective and acceptable solutions [10]. Innovative business models, such as farmers energy communities that use Agri-PVs or cooperative ownership of wind turbines, can provide economic incentives and shared benefits, fostering wider adoption [15]. These models can also address potential trade-offs with other systems, such as land use conflicts and energy distribution challenges. Thus, it is evident that the agricultural sector can more easily integrate RES by utilising cooperative approaches and creative financing mechanisms in order to make farming operations and agriculture production more resilient.

3.2 Cross-cutting recommendations for RES integration in agriculture

The integration of Renewable Energy in agriculture can occur at various levels, encompassing both transformations in farm management and production processes. These levels of integration range from the implementation of small-scale, on-farm renewable energy systems to comprehensive shifts in agricultural practices, farmers behaviours and production methods. Understanding these stages is crucial for evaluating the trade-offs and synergies within the environment, renewable energy and agricultural production interplay.

Several key factors influence the successful integration of RES at the farm level, including the **level of application across farm operations**, the **availability of energy storage systems for continuous operation**, the **implementation of robust energy management systems to optimize production and grid interaction**, the **extent of changes in operational practices (including changes in business operations), logistics, and behaviours** and lastly the **effect** that this integration can have **in farm's production**.

Based on these factors, we categorize integration levels into three distinct tiers:

- **High integration:** comprehensive adoption across all farm operations, incorporation of energy storage solutions, advanced energy management systems, and significant adjustments in operational practices, logistics, and behaviours. Significant effects in farm's production.
- **Medium integration:** partial implementation across various farm operations, limited energy storage capacity, basic or average energy management systems, and some noticeable changes in operational practices. Moderate effects in the production of the farm.
- **Low integration:** minimal application in farm operations, absence of energy storage solutions, limited energy management capabilities, and negligible changes in operational practices, logistics, or behaviours [16]. Minimal effect in the production of the farm.

In order to achieve high integration, the following cross-cutting good practices can be applied, using both technical and socio-economic levers.

Technical levers

- Integration of RES within farm infrastructure and operations
  - **Integrating renewable energy solutions directly into farm operations**, such as using solar-powered irrigation systems, wind-powered water pumps, or biogas for heating and electricity, enhances energy efficiency and reduces operational costs across various farm types [17,18].
  - This integration can be supported by the **electrification** of farm infrastructure and machinery. Where electrification is not possible (e.g. for some heavy-duty machinery), fossil fuels should be replaced by **alternative fuels** [17]. One solution is the transformation of solar energy into hydrogen production, which can in turn be used to fuel the heavy-duty machinery still needed on-farm [17].
  - **Utilizing existing farm infrastructure**, such as irrigation systems for small hydropower or rooftops for solar panels, can reduce costs and improve overall efficiency [19,20].
- Combining different renewable energy sources
  - Combinations such as **wind-PV hybrid systems** or **integrating biogas and solar power** can provide a more stable and reliable energy supply suitable for diverse farm types [21].

Moreover, in specific areas, **combining micro-hydropower with solar PV** can be advantageous both in terms of grid connection and storage capacity [22].

- Improving energy storage capacities
    - Improving energy storage capacities on farms is crucial for maximizing the benefits of renewable energy. Implementing **advanced battery storage systems** allows for storing excess energy generated from renewables [10]. **Thermal energy storage** can efficiently manage heating and cooling needs, especially in greenhouses [23]. Additionally, adopting **hydrogen storage technologies** enables clean energy storage and utilization, enhancing overall energy efficiency and resilience on the farm [20].
- Improving energy efficiency and reducing energy consumption on farm
    - RES integration on farm and within farming landscapes and communities should be coupled with **a holistic approach to energy efficiency** to avoid the potential rebound effect sometimes associated with the substitution of high emission or high pollution technologies with "clean" technologies.
    - Implementing **building management systems** (BMS) for agricultural constructions, **efficient heat management**, and **livestock building energy upgrading/renovation** are crucial [17].
    - Key best practices also include **precision agriculture techniques**, **precision livestock farming**, and **conservation agriculture**, including the use of **alternative crop nutrient providers** [17].
    - Additionally, **adopting less input-demanding crop varieties and animal breeds**, and **reducing water demand and losses**, are essential steps to enhance energy efficiency and sustainability at the farm level [17]. On an indirect level, **ensuring energy-efficient fertilizer and machinery manufacture is also key** [17].
- Energy management systems and grid interactions
    - **Energy management systems** can play a vital role in optimizing farm energy use and **facilitating interactions with the grid** [24, 25]. By monitoring and controlling energy consumption and generation, energy management systems enhance efficiency and enable demand-response strategies [26]. This integration supports grid stability, allows for better utilization of renewable resources, and can lower energy costs for farmers [16].
- Promoting circular bioeconomy practices, carbon sequestration and GHG emission reduction
    - **Utilizing waste and residues for energy production**, such as in biomass and biogas systems, adds extra value to farm operations [3].
    - Along with circular economy approaches, supporting **holistic approaches to farm decarbonisation and climate resilience**, integrating both **soil carbon sequestration** and **GHG emission reduction**, is key.
    - Practices that enhance **soil carbon sequestration** at the farm level include: Crop rotation, Soil coverage, No/minimum tillage, Nutrient management, Crop diversification [17]. The use of RES integration by-products such as biochar is also relevant [27].
    - **Carbon farming business models** can support the adoption of such practices.

- **GHG emission reduction practices** should target both **CO_2 emissions** – from energy combustion (off-road vehicles, greenhouses), from land use and land use changes in cropland and grassland – and **non-CO_2 emissions** – methane (CH_4) and nitrous oxide (N_2O) from livestock (manure management and enteric fermentation) as well as N_2O from agricultural soils [28].
- **Agroecological practices** can enhance soil carbon sequestration and mitigation efforts at the farm level, and, coupled with RES integration, can make the farms more climate resilient.

- Assessment, Monitoring, and Evaluation
  - **Thorough assessments of site conditions, resource availability, and technology suitability** are necessary to ensure optimal integration and performance of RES systems [24,29]. **This can be done via farm energy audits.**
  - **Continuous monitoring and evaluation post-implementation** are vital for optimizing performance and facilitating improvements, enabling the early detection of any issues [17,18].

Socio-economic levers

- Education and training
  - Firstly, **education and training** are crucial for every RES type and farm type. Farm operators and workers need to be knowledgeable about the specific technologies and their maintenance requirements, ensuring that systems are efficiently operated, and issues are promptly addressed [30].
- Stakeholder engagement
  - **Comprehensive stakeholder engagement during site selection and planning** is essential. Involving local authorities, farmers, and residents in these early stages helps address concerns and gain support, leading to smoother project implementation and ensuring regulatory compliance [17,10].
- Developing sustainable business models and leveraging finance
  - **Community engagement and the formation of cooperatives** play a significant role in enhancing social acceptance and sharing financial risks, making the initial investment more manageable and fostering a sense of ownership among community members [8,18,21]. **Leveraging financial incentives** such as feed-in tariffs, subsidies, and green energy certificates can significantly improve the economic viability of RES projects [8,18].
  - **Forming partnerships with external investors** can also help cover substantial initial costs, particularly for wind and biomass/biogas projects [8,18].

3.3 Recommendations and examples per RES type

This section presents the state of play, challenges, opportunities, recommended best practices, and concrete examples for five RES types: Solar, Wind, Biomass, Hydropower, and Geothermal.

3.3.1 *Solar*

State of play

Photovoltaic panels on existing buildings in the farm powering irrigation systems or greenhouses, solar photovoltaic thermal systems (PVT) that produce hot water for dairy farms, or solar powered machinery are some of the potential applications of solar energy at the farm level (Figure 2). There is growing investment in agrivoltaics projects, combining solar panel set ups with crops or livestock grazing, with potential benefits in terms of land use, biodiversity, and adaptation to climate change. In Europe, the solar energy capacity increased from 164.19 GW in 2021 to 259.99 GW in 2023 [31], showing a growing interest in the area.

Figure 2. Aerial view of agrivoltaics

Challenges

The integration of solar power in agriculture faces several technical, policy, land-use, financial, and societal challenges. For instance, while shading from solar panels can benefit certain crops, it can harm others. Moreover, the existing farm infrastructure may not always be suitable for deploying agrivoltaics or rooftop PV systems [32,33]. Policy-wise, the lack of clear definitions and regulations around agrivoltaics can complicate permitting and grid connection procedures, leading to exclusion from subsidies like those provided by the Common Agricultural Policy [32,33,34]. Additionally, fluctuating electricity prices and the difficulty of storing large amounts of generated energy pose challenges for the competitiveness and efficiency of farms equipped with solar panels [33].

Financially, the high initial investment costs that could even require external investors and the risk of lower-than-expected income deter many farmers from adopting solar power [33,34]. Furthermore, the rise in land prices due to competition between agricultural and solar uses further complicates land-use decisions [34]. Societal acceptance is another significant barrier, as large solar installations can impact landscapes and face opposition from local communities concerned about the use of valuable natural resources, land fragmentation, and perceived unfair distribution of costs and benefits [33,34]. Lastly, issues such as inadequate grid balancing, restricted maximum capacity, and bureaucratic delays exacerbate these challenges, making the integration of solar power in agriculture a complex endeavour [34].

Opportunities

Small increases in PV installations can significantly boost energy production on farmland. For instance, covering just 1% of Utilised Agricultural Area with agrivoltaic systems could generate about 944 GW, which is nearly half of what traditional ground-mounted PV systems yield and approximately five times the EU's installed capacity in 2022 [34]. Innovations such as semi-transparent materials for agrivoltaics can mitigate shading issues, and smaller installations can better fit existing farm infrastructures [21,33]. Another opportunity is to use solar fencing in farms that require fences to produce energy without using any additional space and with a lower cost of installation than other solar applications [35].

Market initiatives like Green Energy Certificates and "feed-in tariffs" provide price stability and long-term contracts, which can facilitate further investments in renewable energy [8,33]. Additionally, by profiling and benchmarking farm energy consumption, significant improvements in energy efficiency can be achieved, enhancing overall sustainability and reducing operational costs [10]. Lastly, studies have shown that Agri-PVs installations can have a positive impact on water systems [14] close to the installations or in the quality of the produced wool by sheep grazing next to them [36], highlighting also the environmental benefits of integrating solar energy installations in agriculture.

Good practices

Implementing solar power in agriculture requires considering technical, agricultural, environmental, and socio-economic factors.

- **Engaging communities and forming cooperatives** can foster local support and participation, ensuring the long-term success of projects [8,33,12].
- **Stakeholder involvement in site selection and planning** is crucial to address local concerns and optimize site suitability [34,10].
- **Continuous monitoring post-implementation** is essential to assess the impact and performance of the installations, ensuring they meet both energy and agricultural goals [32,10].
- **Choosing the right type of photovoltaic (PV) system tailored to specific farm and crop types** is vital for maximizing benefits and minimizing disruptions [32,11]. For instance, crops like leafy greens, clover grass, fruits, berries, herbs, spices and vineyards thrive under agrivoltaic systems, whereas crops like potatoes, bell peppers, broccoli, and winter wheat are less suitable [21].
- **Solar-powered irrigation**, especially in Mediterranean regions, **offers a promising solution for water management**, enhancing sustainability and reducing dependency on traditional energy sources [33].
- **Solar panel designs that create habitats for local flora and fauna** can contribute to biodiversity conservation [14].
- Moreover, research indicates that **solar panel arrays** can positively impact water-stressed lands and influence soil moisture [37], as also can protect the crops from extreme weather events like hail and strong winds [32].
- **Advanced technologies, such as solar-powered nodes, drones and monitoring systems,** can enhance precision agriculture, allowing farmers to manage crops and soil conditions in real-time [38].

- **Solar energy can also propel agricultural machinery, such as tractors,** providing a clean and renewable power source for farm operations [39].
- Regarding agrivoltaics systems, French law integrates the following principles [40]:
  - **Reversibility:** Installations must be designed so that they can be removed without permanently damaging the environment or the agricultural potential of the land on which they are installed.
  - **Maintaining agricultural or pastoral rights:** The installation of solar panels must not suppress or limit existing agricultural or pastoral activities
  - **Servicing soil quality and agricultural yield:** projects should not only improve soil quality, but also ideally increase or at least maintain local agricultural yields, or reduce their decline.

Example – Bellegarde Agri-PVs and Arboriculture

The Bellegarde project, situated in Gard, France, is an example of successful integration between renewable energy and agriculture. Comprising two sites, Château (3.9MW) and Broussan (2MW), the project combines traditional arboriculture practices with high-mounted Agri-photovoltaic panels to create a symbiotic relationship between energy production and crop cultivation. Initiated by AKUO company as a demonstration of the potential of Agri-PV and arboriculture co-existence, Bellegarde addresses sustainability commitments while creating economic benefits for farmers and electricity companies. Its innovative design of taller steel bases with the possibility of moderating the tilt angle of the panels allows the creation of a protected environment under the panels, resulting in increased crop yields and improved management of fungi diseases by protecting the cultivations against extreme weather events and by controlling humidity and evapotranspiration. Moreover, Bellegarde's set-up allows significant reductions in soil degradation and nutrient leaching, that minimize the need to fertilize and reduce the economic costs of crops. The Bellegarde project produces enough electricity to power 865 houses per year and leads to the avoidance of 168 tonnes of CO_2 eq. emissions per year.

The information for the project comes from AKUO's website page dedicated to Bellegarde project and can be accessed here: https://www.akuoenergy.com/akuo-dans-le-monde/tous-nos-projets/bellegarde

3.3.2 *Wind*

State of play

Wind energy is emerging as a significant player in the agricultural sector (Figure 3). Current and emerging technologies include large-scale wind turbines, small wind systems, and hybrid systems combining wind with solar power. These technologies offer numerous applications, such as powering irrigation systems, greenhouses, and other farm machinery. Furthermore, in regions with high wind potential, wind farms can also contribute to the overall energy supply of agricultural operations [41]. However, the adoption rate among farmers varies, with many preferring to lease their land to external investors rather than invest directly in wind turbines [41].

Figure 3. Wind turbines next to agriculture production

Challenges

The integration of wind energy in agriculture faces several challenges. Financial barriers are significant. Most farmers lease their land to external investors due to the substantial financial requirements for planning permission and construction of wind turbines [41]. The high initial costs [41], the maintenance costs especially for small wind turbines systems [41] and the need for comprehensive feasibility studies are significant deterrents. Additionally, obtaining the necessary permits for wind turbine installation involves lengthy and complex procedures, often delaying projects and increasing costs [41].

Social acceptance is another critical challenge. There is considerable hesitancy among farmers and local communities to install wind turbines due to concerns about noise, visual impact on landscapes, and potential property value depreciation [41]. Moreover, there are studies suggesting negative impacts on bird population around the areas that wind turbines had been installed [42]. Furthermore, location suitability is a crucial factor. Wind resource potential and land use planning are critical, as the variability in wind intensity makes it challenging to accurately plan energy output, necessitating advanced management of the power system [43].

Land suitable for wind turbine installation often competes with other agricultural uses, which may be more valued by the local community [10]. Technical challenges can also arise – wind turbines create microclimates that may not be suitable for certain crops due to increased wind speeds and air turbulence [41]. This necessitates careful consideration of which crops to grow in proximity to wind installations.

Opportunities

Despite these challenges, there are significant opportunities for integrating wind energy into agriculture. Wind energy offers a stable source of extra revenue for farmers, particularly in regions with high wind potential [41]. Wind turbines can provide a stable electricity supply if located in suitable areas, reducing dependency on external power sources [41]. Furthermore, comprehensive site planning and stakeholder engagement can reduce the risk and increase acceptance for wind projects [41].

Innovative applications of wind energy can also be explored. For instance, wind energy can be integrated into islanded microgrids for water pumps and desalination systems, providing sustainable solutions for water-scarce regions [41]. Combining wind and solar energy systems can enhance overall energy production and reliability, particularly in greenhouses and other controlled agricultural environments. Moreover, wind turbines can supplement solar energy production in cloud covered days.

Good practices

Implementing wind energy in agriculture requires considering several factors. Technical and scientific considerations are crucial.

- **Selecting the right type of wind turbine** and **ensuring proper site assessment** are essential for maximizing efficiency and minimizing environmental impact [41,42]. **Smaller wind turbines** can be designed to minimize impact on crops and grazing land. **Understanding the microclimate effects** of wind turbines and **selecting appropriate crops** that can thrive under altered wind conditions is also essential.
- Moreover, **integrating wind turbines with grazing** can be beneficial, as livestock can graze beneath the turbines without disruption [41].
- **Wind-PV hybrid systems** can optimize energy production and provide a reliable power source for agricultural operations [41].
- **Engaging local communities** and **forming cooperatives** can address social acceptance issues and distribute the benefits of wind energy projects more equitably [41].
- **External investors** can help cover the initial costs, making wind energy projects more accessible for farmers [41]. Lastly, **ensuring ongoing monitoring and maintenance** of wind installations will help sustain their efficiency and effectiveness [41].

Example – Wind Power for Greenhouses in Southwestern Ontario

The Wind Power for Greenhouses in Southwestern Ontario by Ontario Greenhouse Vegetable Growers, Kruger Energy and the University of Windsor is a pioneering project aiming to integrate wind power in agriculture. Greenhouse vegetable farms in Southwestern Ontario faced energy supply challenges, necessitating a sustainable power source to support their operations and expansion. Kruger Energy set up the project of 200 megawatts of wind power to generate clean electricity and hydrogen, initially focusing on economic and regulatory modelling. The project ended up providing stable electricity to the greenhouses by utilizing the existing wind farms in the region.

The main challenges to overcome at the start of the project were mainly regulatory and economic modelling challenges, but in the end the project was completed through the collaboration of academia, growers' association and energy providers. The project enhances the sustainability of greenhouses operations and provides stable electricity without environmental trade-offs. It also supports the local economy by stabilizing energy costs. The most important success factor in this project was the strong collaborations between growers, academia and energy providers.

The information for the project were drawn from Ontario Greenhouse vegetable Growers and can be accessed here:https://www.greenhousegrower.com/production/wind-power-for-greenhouses-taking-shape-in-canada/

3.3.3 *Biomass*

State of play

Solutions related to the use of agricultural biomass include biogas (including biomethane and biohydrogen), biopower generation (electricity or heat generated by biomass), bio-heat (direct combustion of biomass for heating), biofuels (e.g. bioethanol and biodiesel), as well as the production and use of biomass pyrolysis by-products like biochar. Especially for biogas (Figure 4) there is already a global emerging market influenced by the need for a smoother transition to renewable sources in general, depending on the type of available biomass, different processes can be applied. For instance, wet biomass can produce biogas through anaerobic digestion, and sugars can produce ethanol through fermentation [44]. The different biomass feedstock types available to farmers are energy crops, agricultural crop residues (including animal manure like pig slurry), forestry residues, algae, wood processing residues, and water wastes [45]. Waste-based biomass feedstocks are especially interesting in terms of potential net-positive impact on agricultural production and climate.

Figure 4. Biogas Plant in a farm. Courtesy of Cecilia Burnfield (CKIC) and Bioplex

Challenges

The integration of biomass energy in agriculture comes with multifaceted challenges. Firstly, ensuring a consistent and reliable supply of biomass presents logistical hurdles, with issues ranging from waste collection to crop residue management and cost-effective selection of the most relevant feedstock type [10]. Secondly, financial barriers can be significant, particularly in the initial investment phase, where the costs of setting up biogas infrastructure can be prohibitive [44,46]. Moreover, navigating policy and regulatory frameworks adds complexity [10], requiring compliance with local regulations and obtaining permits, which can often be time-consuming and resource-intensive endeavours [10,24]. Lastly, biomass production and use is not sustainable by default [24,47]. For example, intensive cultivation of energy crops can lead to soil degradation, water stress or pollution, and in some cases competes with the production of food and feed [24]. The European Union does not impose mandatory sustainability criteria related to biomass sourcing and use, or to related land-use changes, but leaves this responsibility to individual member states, which further complicates the existing political and legal framework [24].

Opportunities

Biomass exploitation for energy production on farm can support the farm's economic resilience by diversifying its revenue streams and adding value to farm operations [10]. Moreover, applying a circular economy approach to biomass use can contribute to sustainable resource management and environmental conservation on farmland [10,44]. The use of biochar to reverse soil degradation is an interesting example [46]. Regional-scale business models, coupled with collective approaches such as Combined Heat and Power (CHP) schemes, unlock scalability and foster community engagement [10]. By aligning business models with sustainability goals and exploring diversified biogas outputs, such as heat recovery and biomethane production, biomass and biogas integration holds promise for driving agricultural innovation and resilience [10].

Good practices

- **Engaging cooperatives** and **external investors** can help mitigate financial barriers, promoting collaborative approaches to infrastructure development [10].
- Conducting comprehensive analyses to **select appropriate technology based on crop types** ensures efficient resource utilization while minimizing environmental trade-offs [24].
- Robust waste and biomass require **careful monitoring and management** throughout the production process [24].
- It is also crucial to remain vigilant about potential trade-offs, such as **competition for land and water resources** or increased pressure on ecosystems due to intensified agricultural practices [24].
- Regarding the type of bioresources used for bioenergy production, the **use of agricultural waste and residues** should be prioritized over the use of primary biomass [47].

Example – LIFE SMART AgroMobility Project

The ongoing LIFE SMART AgroMobility project in Spain addresses the environmental and operational challenges of intensive pig farming by converting livestock waste into biomethane for agricultural vehicles and biofertilizers. This initiative emerged to reduce greenhouse gas emissions from unmanaged livestock waste and to provide a sustainable alternative to fossil fuels. The system employs low-cost biodigesters to process pig manure, producing biogas that is refined into biomethane and digestate, which is then used as a high-value biofertilizer. The project significantly reduces CO_2 equivalent emissions and demonstrates the technical and economic feasibility of this waste management model.

The main agricultural-environmental challenge of the project is balancing nutrient management to avoid over-fertilization while maximizing biomethane production. Socio-economically, the project supports local agriculture by reducing energy costs and dependency on synthetic fertilizers, enhancing overall farm sustainability. Initial barriers included technical challenges in biodigester design and ensuring the cost-effectiveness of biomethane production. These were overcome through innovative engineering and collaboration with research institutions. The project's success lies in the integration of advanced waste management technologies and the provision of a renewable energy source for farm operations, demonstrating a replicable model for sustainable agriculture.

The information for this project comes from the LIFE SMART AgroMobility webpage, which can be accessed through the following link: https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE19-CCM-ES-001206/processing-of-livestock-waste-for-the-production-of-biomethane-for-use-in-agricultural-vehicles-and-biofertilizers

3.3.4 *Hydropower*

State of play

From the utilization of existing irrigation systems to the implementation of innovative technologies such as Pump as Turbines (PATs), or smart hydropower with in-stream turbines that use the kinetic energy of the water flow, several options exist for hydropower integration within the agricultural sector (Figure 5).

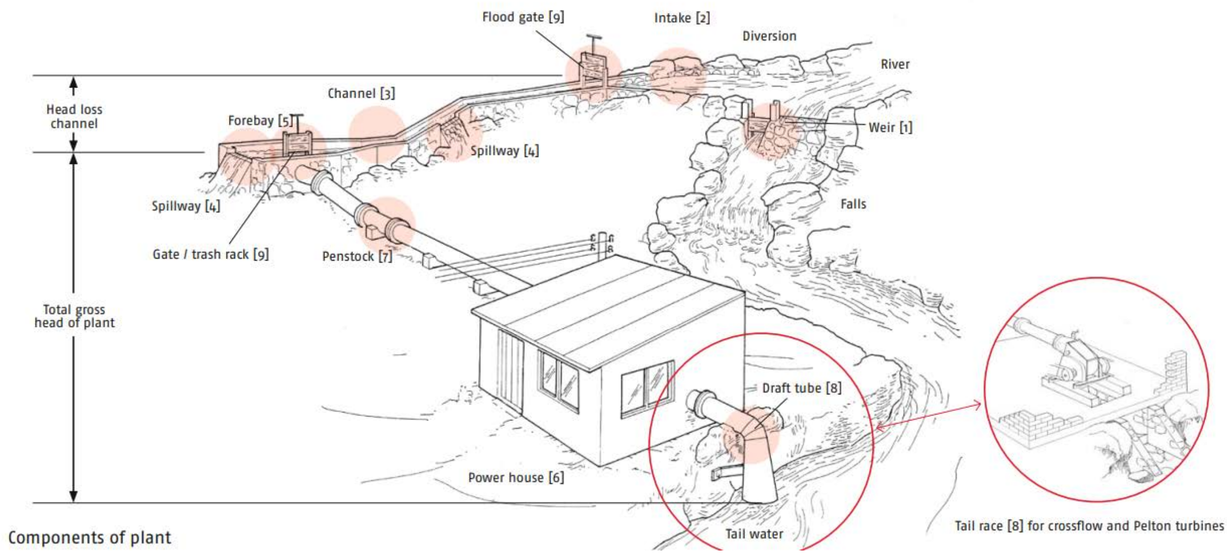

Figure 5. Components of a Micro Hydropower plant [48]

Challenges

For high pressurized systems, the effectiveness of electricity generation relies on specific site conditions, including sufficient water flow and an adequate elevation drop to both pressurize irrigation systems and power turbines [23]. Additionally, different types of turbines are needed to handle varying flow and head conditions, which means turbine efficiency is highly site-specific [23].

A key issue is balancing water use for irrigation and power generation. Reaction-type turbines, favoured for their suitability in low/medium head and high discharge scenarios, often struggle during periods of low water release for irrigation or mandatory flows. This can lead to issues like cavitation, resulting in noise, vibrations, wear, and potential turbine failure [49]. Addressing these challenges requires careful management to optimize the use of water resources for both agricultural and energy needs.

Opportunities

The example of Colorado's law initiative shows that offering a favourable regulatory environment, where most on-farm small hydropower projects can be seamlessly integrated with existing water use without the need for new legal water rights, is a key success factor [23]. Harnessing excessive energy from conduits presents a dual benefit, eliminating the need for new dams or reservoirs and simplifying the permitting process while offering new revenue streams for water system operators [50]. Furthermore, the adoption of Pump as Turbines (PATs) technology enhances the attractiveness of Micro Hydropower (MHP) solutions, offering cost-effectiveness compared to traditional hydraulic turbines for small-scale schemes [51]. Another interesting technology is the use of elevated water reservoirs for water storage that then can be used to make an artificial water stream to generate electricity. Even more those reservoirs can be combined with other renewable sources to be filled. These approaches not only promote sustainability but also contribute to the economic viability of agricultural operations through renewable energy generation [52].

Good practices

- Efficient implementation of hydropower in agriculture **leverages existing high-pressure irrigation systems** to produce hydro energy, offering a cost-effective and straightforward solution. By tapping into the energy already generated within the conduits, this approach minimizes environmental impact and simplifies implementation [23,50].
- However, it's important to note that the technologies that utilize irrigation systems like Pump as Turbine (PAT) and not natural water streams are resource-intensive in terms of water usage, as it requires increased irrigation for optimal functionality. Therefore, **careful consideration of water availability and usage** is essential to ensure sustainable implementation.

Example – PAT power plant in Southern Spain

A pilot Pump as Turbine (PAT) power plant was constructed at a farm located at the left bank of the Genil river irrigation district, in Southern Spain. The motivation behind this initiative stemmed from the farm's desire to reduce energy costs and environmental impact while enhancing sustainability. With existing irrigation systems in place, the farm saw an opportunity to harness the natural flow of water to produce clean and renewable energy.

The implementation involved the installation of PAT technology within the farm's irrigation conduits, allowing for the conversion of excess water pressure into electrical energy. The hydropower system not only provided a reliable energy source but also improved water management practices, optimizing irrigation efficiency and reducing water wastage. This led to minimized environmental impact without significant modifications to the landscape.

Initial challenges included technical complexities in system design and regulatory considerations. But in the end, for the operation time of the project, the savings were 2258€ and 8.4 t eCO_2 and the return on the investment of the plant installation calculated to be paid back in less than ten years.

The information for this example came from the paper by: Chacón, M. C., Díaz, J. A. R., Morillo, J. G., & McNabola, A. (2021). Evaluation of the design and performance of a micro hydropower plant in a pressurised irrigation network: Real world application at farm-level in Southern Spain. The paper can be accessed here: https://www.sciencedirect.com/science/article/abs/pii/S0960148121000914

3.3.5 *Geothermal*

State of play

With current advancements in technology and growing recognition of its potential, geothermal energy is increasingly used for agricultural operations. Geothermal power plants extract hot water or a mixture of water and steam from underground reservoirs to the surface, using the heat to generate steam that drives turbines and produces electricity (Figure 6) [53]. Afterward, the cooled fluids are reinjected back into the reservoir to be reheated and reused [53]. The utilization of geothermal resources for heating purposes, such as soil heating, for the drying of agricultural products, and for greenhouse operations, has gained popularity, particularly in regions with favourable geothermal conditions [54].

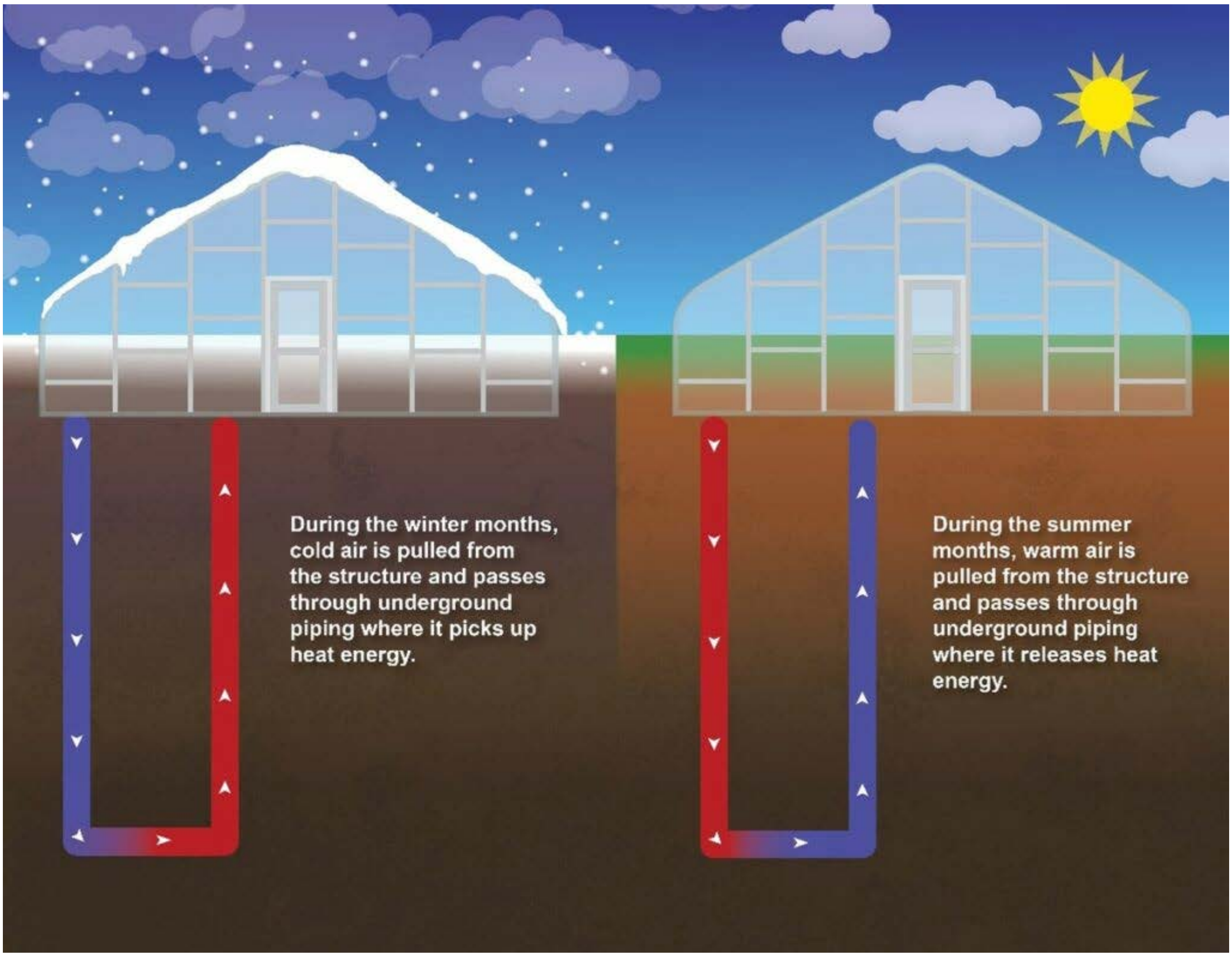

Figure 6. The flow of heat energy in a geothermal system. Adapted from: Marisa Larson, NCAT [53]

Challenges

At the initial phase of geothermal projects, resource risk poses a significant challenge, influencing project financing and investment decisions [54]. Moreover, technology providers may encounter knowledge gaps in implementing geothermal options, especially concerning specific technical issues like corrosive environments [10].

Opportunities

Geothermal applications in heating and cooling for agricultural procedures, such as soil heating, livestock building temperature regulation, and greenhouse operations, present a compelling opportunity to reduce energy costs and reliance on traditional heating methods [54]. Additionally, depending on regional conditions, geothermal heat could serve as a viable option for glasshouse horticulture, providing a consistent and renewable energy source for maintaining optimal growing conditions [10].

Good practices

Implementing geothermal energy in agriculture requires careful consideration of technical, environmental, and socio-economic factors.

- Drawing insights from **innovative governing models**, such as Tuscany's approach to simplifying permitting procedures and incentivizing geothermal energy use, can provide valuable lessons for fostering geothermal adoption in agricultural settings [54].
- Moreover, **leveraging geothermal energy for heating pumps and irrigation systems**, as demonstrated in studies like the one by Alberti et al. [55], can optimize energy utilization and enhance agricultural productivity.

Example – Geothermal Integration at Geothermiki Hellas Farm

Geothermiki Hellas Farm, situated in Greece, is an example of successful integration of geothermal energy into agricultural practices. Facing rising energy costs and the need for sustainable heating solutions for its greenhouse operations, the farm, specialized in dried vegetables and fruits, implemented a geothermal heating system including dryers, utilizing heat pumps to extract heat from the Earth's subsurface for greenhouse heating during colder months.

The geothermal heating system at Geothermiki Hellas Farm relies on advanced heat pump technology to efficiently extract and distribute heat within the greenhouse facilities. By adopting geothermal energy, the farm reduced its reliance on fossil fuels for heating, thereby lowering greenhouse gas emissions and minimizing environmental impact. Additionally, the consistent and renewable nature of geothermal energy enhances agricultural productivity and resilience to climate variability.

The main barriers to implementing geothermal energy in agriculture include initial investment costs, technical complexities, and regulatory considerations. Success relied on comprehensive site assessments, stakeholder engagement, and a clear business case for geothermal integration.

The information for the success story came from the official website of the project and can be accessed here: https://geothermikihellas.gr/

3.4 Beyond the farm

The integration of RES in agriculture can happen within the farm gate (as illustrated by the examples given previously in this report) but can also be envisioned at the level of **value-chains and landscapes**. This means shifting the focus of the discussion from technology to market linkages [56] and rural development strategies [56,57] as part of **integrated or holistic approaches** [56].

Strengthening market linkages entails investment in "physical infrastructure to support on-farm production (irrigation, energy, transportation, pre- and post-harvest storage), efficient trading and exchange, value addition, and improved transportation and bulk storage" [56]. Technologies that facilitate farmers' access to local information about weather, water consumption, diseases, yield, and input and output prices also need to be facilitated [58].

Integration at the level of the community, the region, or the landscape (concepts which sometimes overlap) is also crucial. RES integration can be a key lever for rural development, as part of **"place-based" innovation initiatives** where farmers and neighbouring stakeholders work together to share the benefits of RES infrastructure. Energy communities and local, circular bioeconomy systems (including industrial ecology projects) are examples of this type of approach. In line with this idea, the European Network for rural development recommends considering "all approaches that can be applied to stimulate uptake e.g. individual or joint commitments among farmers and foresters or community-led energy projects involving the wider rural community" [57].

As a conclusion, RES integration should be part of **integrated approaches to transforming food and energy systems**. As recommended by FAO and IRENA, "energy and food systems should be transformed in synchrony to leverage synergies and minimise conflicts", as part of a "holistic approach that considers climate, land, energy and water in an integrated way" [56]. **Integrated food-energy systems (IFES)** can contribute to the optimisation of land use (for example via the combination of mixed-cropping systems, agri-voltaic solutions, and biomass use through cascading uses of manure and other food chain residues).

Such systems should be designed to "fully account for the nexus of energy, food and water" and to "optimise land use and advance circularity in energy-food linkages, recognising and addressing trade-offs and harnessing synergies among sectors." [56]

The FAO suggests the following assessment criteria for IFES sustainability (Figure 7) [59].

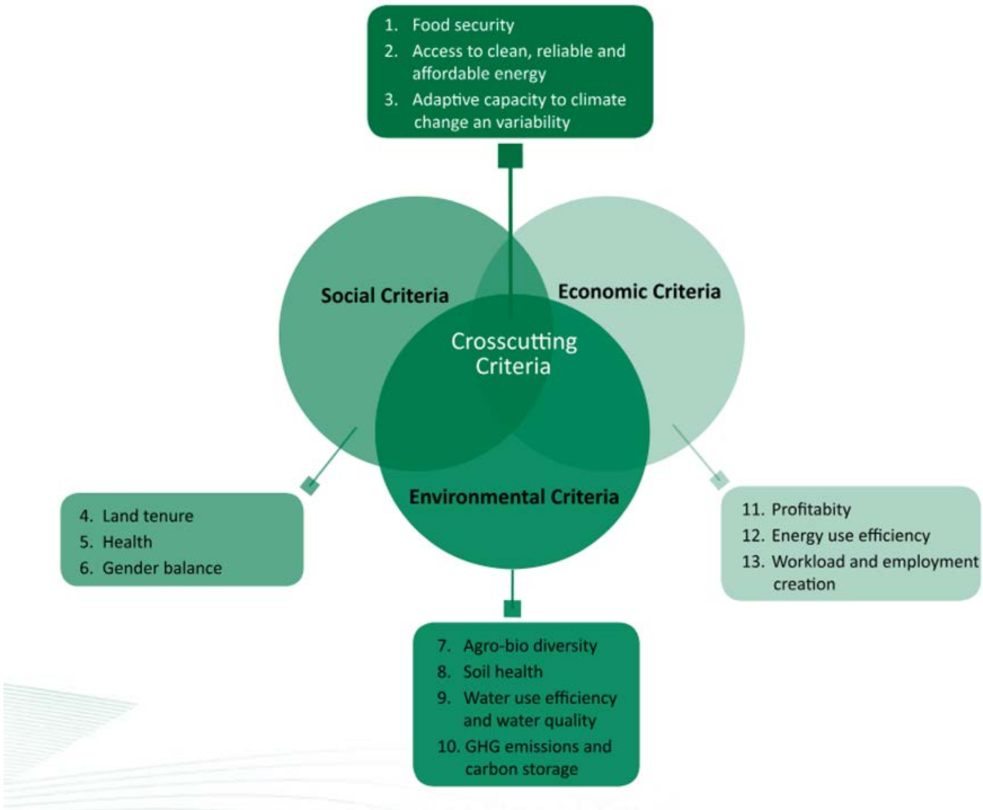

Figure 7. Sustainability criteria for assessing IFES [59]

3.5 Additional resources

Many projects and initiatives have worked on the topic of RES and agriculture before HarvRESt, and many initiatives with complementary ambitions are currently active. A first mapping of these initiatives is presented as an Annex 2 to this report.

The knowledge produced by these projects (which includes policy briefs, research papers, case studies, practice abstracts, project and technology inventories and platforms) is easily accessible online and should be used as much as possible to inform further experiments and demonstrations.

Among this wide ecosystem of projects, the following initiatives provide useful resources that can be used as a starting point for exploration:

- AgroFossilFree [60] (Horizon 2020 funded project, 2020-2023)
    - 59 practice abstracts on de-fossilised EU agriculture (minimum fossil energy dependency), more efficient energy use, optimised agricultural production, reduced GHG emissions, and increased economic, agronomic and environmental benefits.
    - The AgEnergy Platform: https://platform.agrofossilfree.eu/en
- BIOREGIO Interreg- Regional circular economy models and best available technologies for biological streams [61] (2017-2022)
    - Project good practices webpage

- **HyperFarm - Hydrogen and photovoltaic electrification on farm** (Horizon 2020 funded project, 2020-2024)
    - Practice abstracts [62]
- **RES4Live - Energy Smart Livestock Farming towards Zero Fossil Fuel Consumption** (Horizon 2020 funded project, 2020-2024) [63]
    - Practice abstracts
- **EU CAP Network** [64]
    - Good practices platform P5. Resource efficiency and climate https://eu-cap-network.ec.europa.eu/good-practice_en?f%5B0%5D=rdp_priority_all_good_practice%3A728

The ClieNFarms Catalogue of Climate Solutions provides information about farm-level solutions that can reduce climate impact of agricultural production systems in Europe. This catalogue describes good practices for GHG emission reduction and carbon sequestration in 6 agricultural systems: Dairy Cattle, Beef Cattle, Pigs, Sheep, Arable crops, and Perennial crops (Table 1). This solution list is available on the ClieNFarms website [65]. Factsheets are still in development at the time of writing this report.

Table 1. The ClieNFarms Catalogue of Climate Solutions

Solutions	Solutions
Crop/forage production - Diversify crop rotation - Increase crop residues left on the soil - Incorporate crop residues in the soil - Cultivate cover crops - Cultivate legume crops - Cultivate inters own or inter-relayed crops - Grow species or varieties with higher N-use efficiency - Integrate grass leys into arable rotations - Establish and maintain field margins - Establish or maintain hedgerows and individual trees - Establish or maintain agroforestry	Animal Feeding and nutrition - Feed methanogenic inhibitors - Feed nitrate - Increase lipid content of diet - Feed plant secondary metabolites that reduce methane synthesis - Use low-emission feed ingredients - Improve forage quality - Optimize the type and amount of concentrates - Optimize starch content of the diet - Reduce crude protein content of the diet - Reduce feed losses
Fertilization - Adapt fertiliser application - Apply organic fertilizers - Apply low-emission fertilizers	Pasture management - Improve grassland management - Incorporate legumes in grassland - Improve grazing practices - Increase or maintain share of permanent pasture
Soil and water management - Lime soils when required - Reduce soil tillage - Increase water table in peat soils - Apply biochar to soil - Improve or maintain drainage of mineral soils	Animal management - Improve genetic selection for improved performance - Improve reproductive management practices - Improve animal health - Optimize feed ration according to animal requirements - Improve young stock management - Reduce number of unproductive animals
Manure storage and treatment - Clean manure storage tank - Reduce temperature of stored slurry - Capture and treat methane from slurry (oxidation) - Shorten manure storage time - Use air cleaning system - Reduce straw bedding	System management - Convert conventional farming system to organic farming system

4. ASSESSMENT OF THE NEEDS OF LOCAL STAKEHOLDERS AND THE FRAMEWORK CONDITIONS IN THE NATIONAL AND REGIONAL CONTEXTS OF THE HARVREST USE CASES, AS WELL AS AT THE EU LEVEL

Task 2.2 covers the assessment of the needs of local stakeholders in each UC and aims to shed light on the framework conditions in the national and regional contexts of the HarvRESt UCs, as well as at the EU level. As part of this task, the following section presents our findings on the context and framework conditions at the EU level and, more specifically, in the UC countries. The analysis is initially based on desk research results collected at both the EU and UC levels. On top of this, a major aspect of our study is the additional knowledge gained through interviews with regional stakeholders in each UC and a telephone survey conducted among farmers in each UC country.

Task 2.2 contributes significantly to the overall project by enhancing the understanding of public perceptions and exploring the social acceptability of renewable energy projects among farmers and rural communities. This knowledge directly supports Tasks T3.1 and T3.2, which are focused on raising awareness through tailored approaches. Additionally, the framework and guidelines developed in Task 2.2 inform Task 2.5 and aid in forming working groups that facilitate multi-actor engagement at each HarvRESt UC. The social engagement and awareness techniques from Task 2.2 are also instrumental for Task T6.4, where they will be applied in co-creation sessions to improve discussions with UC stakeholders and ensure the methodologies developed are effectively implemented.

The structure of this section is organised as follows: Chapter 1 presents the overall approach and the methodological steps followed. Chapter 2 provides an insightful description of the framework conditions at the EU level, incorporating both desk research and survey results. Following this, Chapter 3 dives into the desk research findings on the UC national framework conditions and includes an analysis of the interview results. Finally, Chapter 4 offers the Discussion section, which synthesises the overall knowledge gained from the three research activities and presents the necessary conclusions.

4.1 Methodology and approach

4.1.1 *Summary of the general methodological approach and timeline*

Task 2.2 employed a blend of methodological approaches to collect input from both primary and secondary sources (Figure 8). Data triangulation, which involves using multiple sources and methods to validate findings, enhances the reliability and comprehensiveness of the results [66,67]. In the **first phase**, targeted **desk research was conducted to gather information on the existing framework conditions for renewables penetration at the farm level across Europe**. In parallel, UC partners performed desk research to collect relevant information for the pilot countries. This involved reviewing relevant study reports, policy documents, and case studies.

The **second phase** involved running a **survey based on the desk research findings and a literature review to identify relevant gaps, targeting the four UCs**. A specialised company collected responses through phone interviews (60 per country), focusing on capturing local farmers' perceptions about regional RES penetration at the farm level, as well as regional needs and challenges.

The **third phase included a round of interviews** targeting regional stakeholders from various sectors, including industry, farmers, local authorities, and energy communities/associations. The aim of these interviews was to **gather insights into the context of farmers and regional communities in the target regions**, with a focus on the regional needs, challenges, barriers, and framework conditions concerning RES uptake at the farm level. The interviews confirmed the information gathered during the desk research and the survey.

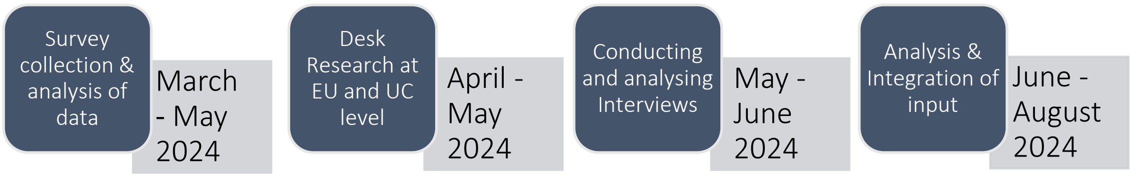

Figure 8. Task 2.2 Timeline

4.1.2 *Desk research at the EU Level*

The rising global energy demand challenges agriculture with increasing costs and environmental concerns. However, renewable energy sources such as solar, wind, and biomass offer a sustainable solution by reducing fossil fuel reliance, enhancing profitability, and promoting sustainability [68,69]. Understanding the needs and challenges of stakeholders is essential for tailoring solutions to regional contexts.

In the HarvRESt project, we identified factors affecting RES uptake by farmers in the EU and conducted a detailed analysis of:

- Socio-economic aspects (e.g., awareness, knowledge gaps, perceived challenges, socio-demographic influences)
- Political and legal aspects (e.g., political frameworks, legal limitations, CAP measures)

We conducted desk research consulting diverse sources, including scientific publications, policy documents, white papers, and national rural development programs. This mapping exercise has a pan-European scope, with a focus on HarvRESt UC countries: Italy, Spain, Norway, and Denmark.

4.1.3 *Semi-structured interviews at the UC level*

As part of T2.2, a series of semi-structured interviews with key stakeholders was conducted at the UC level by the local partners (at least 5 interviews per pilot area).

The purpose of the interviews was twofold. First to examine how, why, and under what circumstances socio-economic factors act as barriers or enablers for the uptake of RES at a farm level. Second, to gain a deeper understanding of the perceived needs and challenges for RES uptake by farmers and rural actors. The interviews complement the other two research methods under T2.2 (Desk research/Survey). This section outlines the methodology followed for collecting regional stakeholders' perceptions, needs and challenges through the interviews.

The process for conducting the semi-structured interviews included the following elements (Figure 9):

- Preliminary Phase: Identification of stakeholder groups and potential interviewees.
- Step by Step procedure to be followed before, during, and after the interview.
- Reporting templates (each tailored for each stakeholder group: farmers, energy communities/industry, public authorities) and Consent form.

Figure 9. Process followed on interviews' implementation

Sampling methodology and Target groups

The interview-based analysis of the needs, specificities, and challenges regarding RES uptake at the farm level was conducted using a semi-structured, in-depth, qualitative study. A well-tailored sampling frame was employed to include participants across various stakeholder groups, including among others, farmers/rural actors, public authorities, energy community members, and representatives of the energy industry. Project partners mapped relevant stakeholders using convenience sampling, leveraging their regional networks to select impactful participants. This process was facilitated through a template (Annex 3), requiring UC partners to list at least five candidates from different stakeholder groups.

Participants were recruited from diverse backgrounds, including the energy industry, local authorities, industry associations, and public administration. Participant privacy was ensured throughout the study, adhering to GDPR principles.

Interview Questionnaire

Partners received four tailored questionnaires (Annex 4.2), to assess regional stakeholders' common perceptions, understanding, needs, and barriers regarding RES uptake at the farm level:

- Questionnaire 1: for farmers and other rural actors such as agriculture cooperatives,
- Questionnaire 2: for energy communities/cooperative members and similar actors,
- Questionnaire 3: for representatives of the energy industry and
- Questionnaire 4: for public authorities.

Each questionnaire (details in Annex 4.1) was customised to address specific topics relevant to each stakeholder group, ensuring a comprehensive understanding of their perspectives. UC partners translated the questionnaires and interviewed in their local languages. Reports on the interviews were written in English.

4.1.4 *Survey*

Objectives, methodology, and background information

This study aimed to collect data on farmers' intentions to adopt RES on their farms. In particular, the survey aimed to identify key knowledge gaps, as well as perceived needs and challenges towards RES uptake by farmers. The survey questions were targeted at the UC countries, namely Spain, Italy, Denmark, and Norway, and were designed to extract information regarding the complex socio-economic barriers and enablers for the uptake of RES at the farm level (see specific Research Questions in Annex 5).

Our study aimed to evaluate the applicability of the Technology Acceptance Model (TAM) [1] in understanding farmers' intentions to adopt RES. To the best of our knowledge, there has been no focused research on TAM scores related to farmers' RES adoption intentions. This research addresses this gap by examining TAM constructs—perceived usefulness, perceived ease of use, and behavioural intention—within the context of agricultural technology adoption [70,71].

Methodological approach

The survey, conducted by an independent global data collection company using the Computer-Assisted Telephone Interviewing (CATI) method, gathered responses from farmers in their native languages. We chose CATI for its efficiency in reaching rural areas with limited internet access, allowing real-time data entry and reducing errors. Telephone interviews also enhance response rates and provide deeper insights into farmers' perspectives on renewable energy sources. Participants did not receive any monetary or other forms of incentives for their participation. The survey was launched at the end of March (M3) and lasted for a month.

Measures & Questionnaire structure

To ensure the survey questionnaire appropriately targeted the RES uptake by farmers, previous related works were carefully reviewed to choose the correct variables to investigate [68, 72, 73,74, 75, 76,77,78,79, 80, 81,82,83]. The research questions and the detailed questionnaire are presented in Annex 5 and 5.2 respectively. The survey questionnaire was first pre-tested by five researchers to check the clarity and consistency of the content.

Data was gathered from the following key variables to assess the farmers' intention to adopt a RES: intention, attitude, perceived ease of use (PEU), and perceived usefulness (PU) based on TAM, economic interest, environmental stewardship, and risk aversion (see Annex 5.1). Moreover, information regarding the demographics was gathered. We additionally collected data regarding the perceived drivers, and barriers to adopt a RES, what energy installations already exist in the local communities and the communication channels farmers like to utilise to obtain new information with respect to new technologies in general.

4.2 Framework Conditions and perceived needs at the EU level

This section of the report outlines the **results of a comprehensive desk research and survey analysis** aiming to collect valuable insights into the socioeconomic context and framework conditions in relation to RES uptake at farms at the EU level. This analysis provides information for understanding the current state of the regions, focusing on the progress concerning potential challenges and opportunities, framework conditions and successful cases.

4.2.1 *EU framework conditions, identified drivers and barriers – desk research results*

The agricultural sector's contribution to the total greenhouse gas (GHG) emissions of the EU stands at approximately 10% [84]. In line with EU targets, emissions are slated to be reduced by 40% by 2030, with a focus on achieving a 30% reduction in sectors not included within the Emissions Trading System (ETS), such as agriculture. Additionally, the EU aims to have RES account for at least 32% of its energy consumption by the same year [85]. The production of renewable energy on farms offers several benefits, including emission

[1] TAM is an information systems theory that explains how to encourage users to accept and utilize new technology (Davis, 1989).

reduction, enhanced supply security, additional income for farmers, and the potential for energy self-sufficiency [84].

The adoption of RES by farmers in Europe is critical for meeting the ambitious climate and energy targets set by the EU. The EU's 2030 Energy Strategy, outlined in the "Clean Energy for All Europeans" policy package, sets specific objectives aimed at fostering sustainability and combating climate change. These objectives include a 40% reduction in GHG emissions compared to 1990 levels, a minimum 32% share of renewable energy consumption, and at least 32.5% energy savings by 2030 [86] Moreover, the EU has established a long-term goal of reducing GHG emissions by 80-95% by 2050, necessitating a significant transition in the energy landscape while enhancing competitiveness and supply security [87].

Agriculture holds substantial technical and economic potential for both producing and utilising renewable energy. With its expansive land surface, the deployment of wind and solar energy parks is feasible, while biomass derived from crop and livestock residues or dedicated bioenergy crops serves as a vital energy source. Rural areas witness the production of various renewable energy forms, including wind, solar, geothermal, and bioenergy, which fosters employment, economic development, and energy security [10].

Numerous renewable energy technologies cater to on-farm energy needs, ranging from bioenergy, solar, wind, and geothermal sources to heat recovery systems. Farmers have the opportunity to integrate these technologies and deliver surplus energy to power or gas grids, contributing significantly to Europe's energy mix. **Despite the economic opportunities presented by renewable energy production, scaling up their uptake in the agricultural sector faces multifaceted challenges stemming from diverse natural, managerial, geographical, and socio-economic factors** [10].

Addressing these challenges requires sound advice, investment support, and risk management to facilitate farmer participation in renewable energy initiatives. Some regions in Europe, such as Eastern Europe, require customized policy interventions and support systems due to land fragmentation, small agricultural holdings, and limited investment capacity. Despite these obstacles, the production and utilisation of renewable energy on farms offer compelling opportunities to diversify farming activities, enhance sustainability, and augment farmers' income, aligning with EU climate and energy objectives while promoting resilient and sustainable agricultural practices across Europe.

Socio-economic factors affecting RES uptake at farm level

A range of socioeconomic factors significantly influence farmers' adoption of RES, including **farming experience, farm size, main occupation, off-farm activities, age, gender, marital status, and education level.** Studies by Otara [88] highlight the importance of personal, farm business, regulatory, and behavioural drivers, with cognitive factors like education being particularly impactful [78]. Contextual factors such as socio-demographic profiles and local knowledge systems shape farmers' climate change adaptation strategies. Research by Grothmann and Patt [89] and Hailegiorgis et al. [90] shows these factors affect perceived self-efficacy and cost efficacy regarding adaptation measures.

Research from outside Europe, emphasises the role of indigenous knowledge in farming technology adoption [91, 92]. Traditional knowledge is also crucial in Europe, particularly in biodiversity and agriculture [93] It is deeply embedded in local communities and passed down through cultural traditions. Reimagining traditional methods through agroecology and RES could address sustainability challenges [94]. Socio-demographic and economic characteristics, like **age, sex, household size, education, and income sources**, determine perceived adaptation efficacy. Social networks influence RES uptake by farmers [95], with interactions within these networks shaping awareness and willingness to adopt RES. However, modern farmers' dominance in these networks can delay information flow to traditional farmers. Incentives and interventions are crucial to balance influence and promote widespread adoption of renewable energy sources [96].

Various socio-economic factors influence farmers' decisions regarding the adoption of sustainable agricultural practices. According to [97], the adoption of sustainable practices requiring initial investments or aimed at reducing pesticide and fertiliser usage is positively related to farmers' knowledge levels. However, there was no significant relationship between knowledge and the adoption of practices already subsidised by policymakers. This highlights the necessity for **policymakers to employ both economic incentives, such as subsidies, and behavioural interventions, like facilitating peer-to-peer knowledge sharing**, to effectively encourage sustainable practice adoption.

Education and experience are also significant factors affecting farmers' adoption behaviour, serving as proxies for their subjective knowledge levels [98]. **Farmers' prioritisation of environmental objectives over social or economic ones** emerged as critical for adopting circular innovations aimed at reducing emissions and improving resource efficiency. Key factors include higher education levels, previous experience with innovation adoption, clearly defined ecocentric attitudes, and being located in vulnerable areas [98] Furthermore, research emphasises the crucial role of **blending financial support with efforts to enhance networking and knowledge dissemination among farmers** to promote sustainable agricultural practices [99] Farmers often seek advice from peers and independent advisors, indicating the need to leverage these communication channels to reach a wider audience, including traditional farmers who may not actively seek information on emerging technologies [100] These findings reinforce the importance of promoting environmental awareness and education among farmers to encourage sustainable practice adoption, considering geographical and environmental factors.

Hindering socio-economic factors affecting the adoption of renewable energy in agriculture are multifaceted. Firstly, landlords' consent is critical, particularly in tenanted farms where landlords may restrict activities perceived as radical, thereby hindering renewable energy initiatives [78]. In Austria, tenant farmers anticipating long-term land access behave similarly to owner-operators, indicating stability and commitment [101]. However, year-to-year leases pose a significant obstacle, incentivising tenant farmers to prioritise immediate production over long-term sustainability [101]. This underscores the need for **cooperation between landlords and tenant farmers to overcome adoption barriers and integrate RES into farming practices**.

Low climate change awareness among farmers is another significant obstacle to adopting renewable energy as a mitigation strategy [102]. Many farmers lack awareness of climate change issues, potentially diminishing their interest in renewable energy solutions. Additionally, small-scale farmers face challenges due to limited information on new technologies and high operational costs [98]. Despite demonstrating entrepreneurial activity through off-farm income, farmers may not fully capitalise on renewable energy opportunities due to perceived risks and insufficient support or incentives [103]

Societal barriers such as visual impacts on landscapes, noise pollution, and odour concerns associated with renewable energy installations also contribute to resistance from local communities [10]. This **resistance may stem from a top-down approach to renewable energy deployment, leading to opposition and undermining the development of appropriate initiatives in rural regions** [104]

Economic barriers to adoption include high costs associated with adoption, such as investment and learning expenses, which may exceed perceived profitability. In Europe, **where small-scale and family farms are prevalent, substantial investment requirements pose significant entry barriers** [105]. Additionally, farmers face considerable uncertainty regarding potential cost savings and additional revenues from novel technologies, leading to doubts about economic benefits [106]. Tackling these economic adoption barriers, such as high investment costs and uncertainties about cost savings, is crucial to motivate farmers and overcome obstacles hindering the widespread adoption of renewable energy technologies. Specific interventions and incentives are required to alleviate the economic risks associated with adopting renewable energy technologies in agriculture.

The following Table 2 summarises the socio-economic factors affecting the update of RES by farmers in Europe.

Table 2. Socio-economic factors affecting the uptake of RES by farmers

Socio-Economic factor	Description	Type
Education Level	High education level (university education) positively influences adoption behaviour. Represents farmer's subjective knowledge level and understanding of farming activities.	Driver
Experience	Farmers' experience in agriculture correlates positively with the adoption of sustainable practices. Reflects the accumulated knowledge and skills gained through practical farming activities.	Driver
Financial Support	Access to financial support facilitates adoption by reducing initial investment barriers. Subsidies and incentives provided by policymakers enhance the feasibility of adopting sustainable practices.	Driver
Knowledge Sharing	Peer-to-peer knowledge sharing among farmers enhances adoption rates. Independent advisors and neighbouring farmers serve as important sources of information and guidance.	Driver
Environmental Objectives	Farmers' prioritisation of environmental goals over social or economic objectives positively influences adoption behaviour. Reflects farmers' commitment to environmental sustainability and resource conservation.	Driver
Awareness and Communication	Environmental awareness and education initiatives promote the uptake of sustainable practices. Effective communication strategies increase farmers' understanding of the benefits and implementation methods of sustainable practices.	Driver
Location	Geographic location, including vulnerability to climate change impacts, affects adoption decisions. Farmers in vulnerable areas may be more inclined to adopt sustainable practices to mitigate climate-related risks.	Driver
Landlord Consent	Landlords' permission is crucial, especially on tenanted farms, as their consent may facilitate or hinder the adoption of renewable energy.	Barrier
Low Climate Change Awareness	Limited awareness among farmers about climate change could impede their interest in investing in renewable energy.	Barrier

Socio-Economic factor	Description	Type
Lack of Information and High Costs	Small farmers face challenges due to the lack of information about new technologies and the high costs associated with their adoption.	Barrier
Passive Attitudes and Limited Support	Farmers may display passive tendencies toward adopting renewable energy, exacerbated by limited support or incentives.	Barrier
Visual Impact and Environmental Concerns	Concerns about the visual impact and environmental effects of renewable energy installations may lead to resistance from local communities.	Barrier
Top-Down Approaches and Community Opposition	Large-scale, top-down approaches to renewable energy may face opposition from communities, hindering their development.	Barrier
Logistical and Environmental Considerations	Logistical challenges and environmental factors can act as barriers to the adoption of renewable energy technologies.	Barrier
High Investment Costs and Uncertainties	High investment costs and uncertainties about cost savings deter farmers from adopting renewable energy technologies.	Barrier

Legal and political factors affecting RES uptake at the farm level

The legal framework and political environment within which farmers operate play a crucial role in shaping their decisions regarding the adoption of RES. Legal regulations, policies, incentives, and government support programs directly influence the feasibility, accessibility, and attractiveness of RE options for farmers. Several studies have confirmed that the **Common Agricultural Policy (CAP) significantly influences farmers' decisions regarding the adoption of energy crops and technologies for renewable energy production** in the coming years [107]. Moreover, political agendas and priorities, regarding energy and environmental issues can either facilitate or hinder the uptake of RE initiatives in the agricultural sector. As such, understanding the EU legal and political landscape is essential for farmers seeking to transition towards sustainable energy practices (Table 3).

The uptake of RES by farmers in Europe is influenced by various legal and political factors. Supportive government policies and financial incentives are crucial. **Direct payments and tax reduction schemes from public institutions promote investments in emission reduction solutions** [98] These initiatives align with EU policies, especially within the CAP, facilitating the transition towards sustainable agricultural practices and fostering renewable energy technology adoption among farmers.

Interventions addressing climate change mitigation and adaptation further support farmers' decisions to adopt innovative technologies [98]. **CAP-supported subsidies and targeted measures within the livestock sector, such as yearly subsidies for emission-reducing innovations and lower-tax schemes, incentivise renewable energy**

adoption [108] Government initiatives like the Farm to Fork strategy highlight the importance of support for a just transition towards sustainable agriculture [56]. **Feed-in tariffs also provide significant financial incentives**, encouraging investment in renewables [103].

However, several legal and political barriers hinder RES adoption among farmers. **Planning and zoning restrictions, particularly in national parks, and regulatory uncertainties deter investment** [103]. Obtaining permits for RES systems is often complex and time-consuming due to conflicting regulations on spatial planning and land ownership [10]. **Regulations governing the sale of self-produced renewable electricity can also affect the profitability of RES systems**. Streamlining permitting processes and providing clearer guidelines are essential to address these barriers.

Coordination challenges among various policy sectors complicate rural renewable energy initiatives [104] National energy policies drive incentive schemes for renewable energy deployment, but the complex policy context spans multiple sectors, leading to confusion and conflicting objectives. **A top-down industrial policy approach risks isolating renewable energy from the broader rural economy**, undermining its potential for sustainable development [104] Inconsistent political support and changing policies create uncertainty among investors [109].

Grid infrastructure inadequacies also hinder renewable energy deployment. Electricity grids often lack the capacity to absorb small-scale renewable energy generation, favouring large installations over smaller, decentralised plants [104] This mismatch stalls renewable energy projects or necessitates costly on-site storage solutions in regions like Puglia (Italy) and Scotland. Addressing these challenges requires coherent policy frameworks that align renewable energy objectives with broader rural development goals and promote synergies across policy sectors.

Table 3. Legal & political factors affecting the uptake of RES by farmers (own elaboration)

Legal & Political Factor	Description	Type
Direct payments for emission reduction solutions and tax reduction schemes	Government and public institutions provide financial incentives to support investments in emission reduction solutions and offer tax reductions to encourage the adoption of renewable energy technologies among farmers. These measures align with EU policies, particularly within the CAP, aimed at promoting agricultural sustainability.	Driver
Climate change mitigation and adaptation intervention schemes	Structural one-off subsidies and intervention tools are designed to endorse farmers' decisions to adopt innovative technologies for emission reduction and mitigation. These interventions, supported by CAP, provide financial assistance and incentives for farmers to implement sustainable practices and technologies, contributing to the uptake of renewable energy solutions.	Driver
Regulatory and non-regulatory initiatives within the Farm to Fork strategy	The Farm to Fork strategy includes regulatory and non-regulatory measures to support a just transition towards sustainable agriculture and renewable energy production. It encourages farmers to reduce emissions through the implementation of anaerobic digesters, energy efficiency measures, and investments in solar production, prioritised within the Union's CAP.	Driver
Feed-in tariffs	Feed-in tariffs serve as significant drivers for the uptake of renewable energy technologies among farmers. These tariffs provide financial incentives that	Driver

Legal & Political Factor	Description	Type
	encourage investment in renewables and play a crucial role in promoting the adoption of renewable energy solutions by offering favourable terms for energy generation and feed-in to the grid.	
Planning restrictions, regulations, and uncertainty	External environment barriers, such as planning restrictions and industry uncertainty, discourage farmers from investing in RES. Obtaining permits for RES systems can be complex and time-consuming, with conflicting regulations regarding spatial planning and land ownership. These barriers hinder the deployment of RES on farms and affect their profitability.	Barrier
Lack of policy coordination	The complex policy context for renewable energy, spanning multiple sectors and policy frameworks, poses coordination challenges. Incentive schemes, often driven by the national energy sector, may lack coherence with other policy objectives, generating confusion and hindering renewable energy integration into the broader rural economy.	Barrier
Lack of attention and unstable political support	Inadequate attention from local authorities, along with unstable political support and fluctuating policies promoting renewable energy initiatives, hampers the penetration of RES in rural areas. Investors are sensitive to political risk, necessitating the transfer of such risks through political risk insurance to ensure investment stability.	Barrier
Inadequate electricity grid infrastructure	The insufficient co-ordination between renewable energy deployment and grid improvements results in limited grid capacity to accommodate small-scale and localised generation. The existing grid infrastructure, designed for centralised power plants, favours large installations over small-scale renewable energy projects, hindering renewable energy development in rural regions.	Barrier

4.2.2 *Stakeholder needs and perceived challenges - Survey results*

In the following section, we explore the findings of the survey by analysing collectively all sample responses. By combining the data, we achieved a more reliable and comprehensive understanding of different EU agricultural contexts and patterns. This approach allowed us to present common trends, needs, and challenges identified across the EU in a more robust manner. The statistical analysis conducted provides valuable insights into these overarching themes. Additionally, Annex subsection 5.4 includes the descriptive analysis results of the survey responses for each UC country, offering further detailed insights at the national level.

Survey Analysis

Data collection

In order to analyse the data gathered and gain meaningful insights into farmers' intention to adopt a RES, we followed the following comprehensive process: (i) Data cleaning and preprocessing; (ii) New feature extraction combining related questions; (iii) Exploratory data analysis (EDA), visualisations, and descriptives, (iv) Regression model to infer the farmers' intention to adopt a RES; (v) Path analysis to validate the TAM. By adopting this pipeline, we aimed to obtain a robust sample size for analysis (n=240), representative of the farmers' population in the four UC countries. In the end, we gathered 60 farmers from each country as depicted in Figure 10.

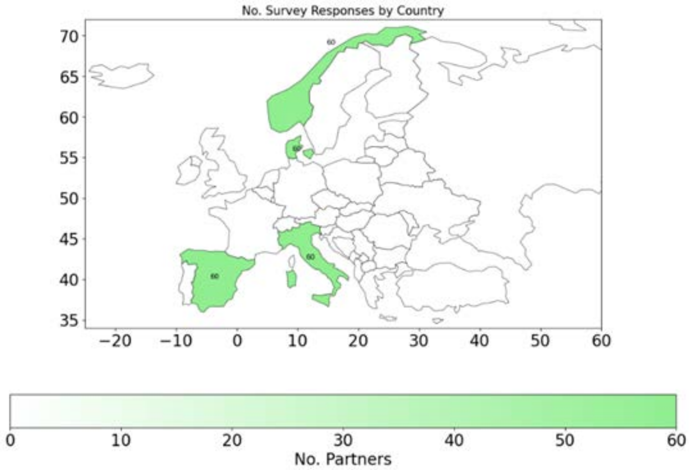

Figure 10. Geographical distribution of the survey respondents

Data exploration

The analysis' initial step involved running an EDA. The EDA aimed to identify data patterns, participants' profiles, meaningful statistics, and errors or missing values.

Concerning the sample of participants, the majority of them are males, have attended some college, and of high annual incomes (Figure 15, Figure 16, Figure 17). Males represent 71% of the sample, 39% of the respondents have attended some college, and 32% have annual household income above 75K€. The low participation of females in the survey could be indicative of a broader trend in the EU farming sector in general [2], where women may not be as active or represented as men. The age of the survey participants ranged from 25 to 71 years old with 50.5 being the average age. For the detailed demographic profiles of the survey participants in each UC country, explanatory graphs are included in the Annex 5.4.

Information was collected regarding participants' previous farming experience and the farms the participants were currently working at (Figure 18). Most participants had more than 9 years working on farms and wholly owned the farm they were currently working on. The largest percentage of the farms is more than 100 ha and has crop production as a primary focus.

The responses regarding the barriers and drivers for establishing a RES are visualised in Figure 11. In the word clouds, the bigger the font size the more frequently the response was chosen. Thus, **the most influential barriers to establishing a RES seem to be the negative impact on wildlife and birds, and the financial barriers, such as high interest rates, low farmer income, and high maintenance/installation costs**. On the other hand, **environment protection, clean energy, economic profit, and energy availability appear to be the most important perceived drivers for adopting a RES**.

[2] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Farmers_and_the_agricultural_labour_force_-_statistics

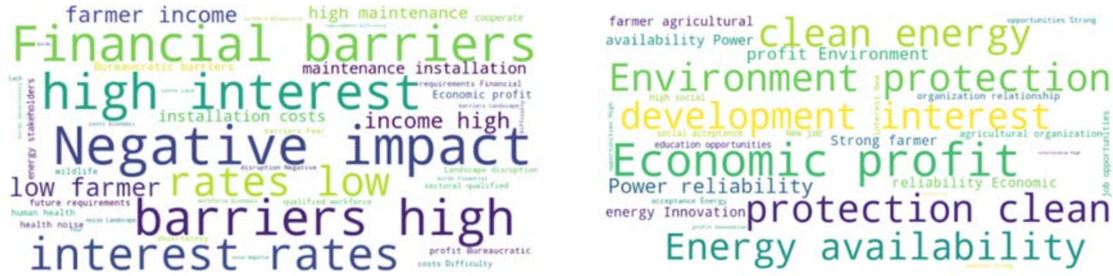

Figure 11. Potential barriers to establishing a RES (left); Potential drivers for establishing a RES (right)

Additionally, farmers were asked about the RES installations existing in their local communities (Figure 31). It was found that **the most common renewable energy technologies are photovoltaics** (PVs) (30.53%) **followed by wind energy** (18.07%) **and biomass energy** (17.13%).

Participants were also asked about their preferred communication channels to acquire information regarding new technologies (Figure 12). The respondents chose hierarchically the following **channels as their most favourable ones: other farmers, cooperatives/associations, and independent experts**. This preference order reveals several key insights into the dynamics of information dissemination within the agricultural community. the top choice, "other farmers," highlights the **importance of peer networks in the agricultural sector**. Farmers often rely on the experiences and advice of their peers because they face similar challenges and share common goals. This trust in peer networks suggests that informal, word-of-mouth communication is a highly effective method for spreading new technological information. It underscores **the need for creating and supporting farmer networks and communities to facilitate knowledge exchange**.

Secondly, **cooperatives and associations ranked as the second most preferred channel**. These organisations play a crucial role in aggregating resources, knowledge, and support for farmers. They act as intermediaries that can bridge the gap between individual farmers and broader technological advancements. By leveraging the collective power of these groups, farmers can access more comprehensive and reliable information. This preference indicates that initiatives aimed at strengthening cooperatives and associations could significantly enhance the adoption of new technologies.

Lastly, **independent experts were the third preferred source of information**. These experts, who may include agricultural scientists, extension workers, and consultants, provide specialised knowledge and impartial advice. Their expertise is essential for understanding complex technological solutions and their practical applications.

Figure 12. Communication channels used to obtain information regarding new technologies

Survey Statistical analysis results

Regression model

Starting the analysis, a regression model was deployed to infer Intention (dependent variable) using a set of independent variables (IVs) containing the basic demographics and the drivers and barriers in adopting a RES. The results of the regression model are documented in the Annex 5.5. It was found that income and energy availability significantly influence RES adoption. Specifically, the identified negative relationship between income and intention suggests that **higher income significantly decreases the intention to adopt RES**. This counterintuitive finding suggests that individuals with higher incomes may perceive less immediate financial benefit from switching to RES or may already have established energy sources. Conversely, the positive relationship between energy availability (D2) and intention indicates that **higher energy availability increases the intention to adopt RES**. This could be due to better infrastructure and greater awareness of the benefits associated with renewable energy in areas with higher energy availability.

It was also found that farm size affects the intention to adopt RES on farms, albeit to a lesser degree. Specifically, **farm size was reported to have a negative effect on adoption intentions**. Farmers with smaller farms demonstrated a greater willingness to adopt new technologies compared to those with larger farms. This finding reveals that **smaller farms exhibit a greater willingness to adopt RES**, which can be strategically interpreted to enhance RES uptake across the agricultural sector. By tailoring incentive programs such as subsidies, grants, and tax breaks specifically for smaller farms, financial barriers can be significantly reduced, making RES investments more attractive. Educational campaigns that highlight success stories, coupled with workshops and training sessions, can equip small farm owners with the knowledge and confidence needed to implement RES. Additionally, **providing technical support and fostering collaborative models, such as cooperatives and community projects, can further alleviate individual costs and enhance the collective benefits**. Implementing pilot programs and funding research focused on the unique needs of small farms can also drive innovation and refine best practices. Furthermore, **advocating for supportive regulatory frameworks and market access can ensure that small farms are well-positioned to adopt and benefit from RES**. By leveraging these strategies, policymakers and stakeholders can effectively promote sustainable energy practices within the agricultural sector, leading to greater energy efficiency and environmental sustainability.

<u>Path Analysis</u>

In this section, we present the findings from our path analysis. Path analysis is a method used to understand how different factors influence each other and their overall impact on an outcome. This analysis aimed to determine the effects of economic interest, environmental stewardship, and risk aversion on the TAM concerning the adoption of RES in the agricultural sector.

Upon running the path analysis, we observed that both environmental stewardship and risk aversion significantly influenced the intention to adopt RES, while economic interest did not show a statistically significant effect. The detailed results, highlighting only the statistically significant paths ($p < 0.05$), are depicted in Figure 13. Comprehensive results, including all paths and their respective coefficients, are presented in annexed Table 16.

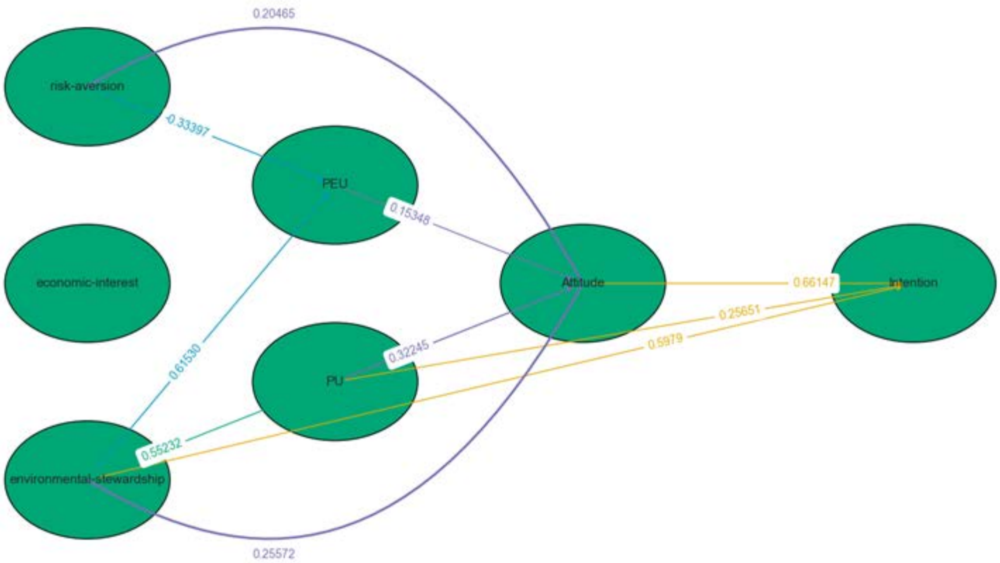

Figure 13. Path diagram for extended TAM model results

To further validate our initial results, we re-ran the path analysis while controlling for additional demographic variables, including income, education, and gender. The statistically significant results from this secondary analysis (illustrated in annexed Figure 32) mirrored the pattern observed in the initial analysis, thereby reinforcing the robustness of our findings.

Key Findings with Controls:

- Income: When controlling for income, the significant paths from environmental stewardship and risk aversion to RES adoption intentions remained consistent, suggesting that these relationships are not confounded by income levels.
- Education: Similar to the income control, the inclusion of education as a control variable did not alter the significant paths identified in the initial analysis, indicating that educational background does not significantly moderate these relationships.
- Gender: The gender control also did not affect the significant paths, suggesting that the effects of environmental stewardship and risk aversion on RES adoption intentions are consistent across genders.

Overall, our path analysis validates the applicability of the TAM in the context of RES adoption within the agricultural sector. The primary drivers for RES adoption appear to be rooted in environmental concerns rather than economic incentives. This highlights the importance of promoting environmental benefits when encouraging the adoption of RES among farmers. Moreover, the robustness of our findings across different demographic controls underscores the reliability of our results.

The use of RES in agriculture is significantly influenced by environmental stewardship and risk aversion, with economic interest playing a lesser role. These insights are crucial for policymakers and stakeholders aiming to design effective interventions to increase RES adoption in this sector.

Conclusion

The survey results reveal that **environmental stewardship is the primary driver for adopting RES in the agricultural sector**. This finding underscores the significant role sustainability concerns play in shaping attitudes toward new technologies in agriculture. The study validates **the applicability of the TAM in this context, with PEU and PU emerging as critical factors influencing farmers' attitudes and intentions towards RES adoption**.

The analysis also shows that risk aversion has an indirect influence on adoption intentions, suggesting that **strategies to mitigate perceived risks could effectively enhance RES uptake**. Interestingly, **economic interest was not found to be a significant driver**, even when controlling for demographic variables such as income, education, and gender. This consistency highlights that environmental concerns and perceived technology attributes outweigh demographic differences in driving RES adoption.

The path analysis provides a comprehensive understanding of these factors and offers actionable insights for policymakers and stakeholders. Key strategies to promote RES adoption should focus on enhancing environmental stewardship, addressing risk perceptions, and simplifying technology use. These targeted approaches can support the agricultural sector's transition toward sustainability. Detailed statistical results and path coefficients, available in Annex 5.5, offer a solid foundation for developing effective interventions and policies.

4.3 Framework Conditions and perceived needs at the EU level

In this section, the framework conditions and factors affecting RES uptake at farms in the UC countries is presented. This exploration will include the **results of our desk research, as well as interviews conducted with key stakeholders, providing insights into the specific challenges and opportunities within different regional contexts**. Additionally, we will offer an **overview of the stakeholders' needs**, highlighting the essential requirements and considerations for promoting successful RE adoption in the agricultural sector.

4.3.1 *Italy*

Overall Framework conditions

RES have become central to Italy's energy policy due to concerns over fossil fuel dependency, foreign energy reliance, and the need to reduce greenhouse gas emissions. Italy has made significant strides in clean energy adoption, reaching its 2020 renewable energy consumption target of 17% in 2014, with renewables constituting 17.1% of energy capacity [110]. Despite progress slowing since 2021, renewable energy generation reached 40.5% in 2021 [111]. The growth has been driven by increased PV, wind, and hydroelectric energy production, averaging 800 MW of new renewable capacity annually between 2008 and 2021.

In 2022, Italian electricity consumption was 306 TWh [112], with renewables contributing around 37% [113], particularly from hydroelectric generation returning to historical levels. Regionally, hydro and bioenergy are more prevalent in the north, while solar and wind energy dominate in the south, creating challenges in managing electricity flows across the national grid. Future trends indicate continued growth in PV capacity in the north and wind installations in the south and islands.

Italy's long-term strategy for reducing greenhouse gas emissions and achieving European decarbonisation goals is outlined in the Piano Nazionale Integrato Energia e Clima (PNIEC), targeting a radical shift in the energy mix towards renewables. PVs are highlighted as a key technology due to their national potential and competitive cost, with goals of at least 40 GW of new wind and PV capacity by 2030 and an additional 70 GW by 2050 [114]. Italy's agricultural sector, the second-ranked in the EU-28, faces challenges in technological innovation, with limited adoption of Information and Communication Technologies (ICT). The Italian Ministry of Agricultural, Food and Forestry Policies has implemented initiatives to promote Sustainable Farming Technologies (SFTs), aiming to increase their adoption from 1% to 10% of the national Utilised Agricultural Area (UAA) by 2021, reflecting a commitment to advancing technology in agriculture.

Socio-economic factors

Socio-economic factors (Table 4) such as farmer age, education, farm size, and labour intensity significantly influence the adoption of renewable energy sources (RES) among Italian farmers [115]. Younger, educated farmers with larger operations show greater readiness to adopt RES technologies, driven by efficiency gains and labour savings [115]. These factors underscore the evolving landscape of renewable energy adoption within Italy's agricultural sector, shaping future policies and investments to enhance sustainability and economic viability. Economic considerations are paramount, with income levels, financial incentives, and the cost-efficiency of technology playing significant roles. Policies like feed-in-tariffs (FIT) and fiscal incentives significantly impact adoption rates by reducing the financial burden of installation and operation [116].

Investments in Italy have predominantly favoured PV and wind sectors, with declining interest in hydro and biomass despite growing biogas investments across Europe. High energy prices, influenced by elevated energy excise duties and substantial fossil fuel subsidies, further complicate Italy's energy market dynamics. The country's focus on large-scale ground-mounted PV installations, while cost-effective, highlights the potential of agrivoltaics to diversify and expand the renewable energy sector, supported by targeted financial incentives to foster social acceptance.

Table 4. Socio-economic factors affecting RES uptake at the Italian UC

Socio-Economic factor	Description	Level	Type
Lack of information	The farmers ability to access incentives is low.	Local and regional	Hindering
Economical convenience	Financial capacity of the farmers in the area is limited.	Local	Hindering
High costs	Maintenance costs are still high.	Local and regional	Hindering
Economic policy	The high price of energy is leading consumers towards alternative energy sources.	Regional	Enabling

Legal and Political Factors

Italy's energy landscape confronts significant challenges due to heavy dependence on imported coal, oil, and natural gas, exposing the country to price volatility and geopolitical risks. Diversifying energy sources and advancing sustainable strategies are imperative to enhance energy security. Policy interventions, investment incentives, and technological innovation are pivotal in this multifaceted approach, requiring collaborative efforts at both national and European levels to ensure resilience and sustainability (Table 5).

Despite progress, Italy's renewable energy investments lag behind neighbouring countries like Germany and Spain. Initiatives such as Green Certificate Systems and the Remuneration of Renewable Energy Resources (REM) aim to spur growth but require substantial infrastructure improvements and government support. Green certificates, overseen by the GSE, incentivise green pricing among companies by certifying annual electricity production [117]

Political uncertainty, high initial costs, and bureaucratic hurdles hinder investment, underscoring the need for stable policies and streamlined regulatory processes to attract long-term financing [118].

Italy has implemented a range of incentive initiatives to foster the adoption of renewable energy technologies in its energy market. These include mechanisms like FIT for smaller plants and Feed-in Premiums (FIP) for larger ones, with differentiated structures based on plant size and operational timelines [119]. PV systems have benefited from schemes such as the 'Conto Energia', introduced in 2005, which provided incentives based on cumulative annual cost thresholds [120]

Recent legislation is enhancing opportunities for renewable energy applications in agriculture, including agrivoltaic practices. Italy now boasts five significant regulations governing agrivoltaic systems, such as the D.M. July 5, 2012 [121] which initially encouraged the development of PV greenhouses in agricultural contexts. Despite these advancements, there remain areas for refinement, particularly in the categorisation of plant typologies and delineation of prohibited areas, to ensure clarity and consistency in regulatory application [122,123] These legislative measures aim to spur innovation in national agricultural activities, fostering efficiency and competitiveness while integrating green energy generation.

Table 5. Legal and Political factors affecting the uptake of RES at the Italian UC

Socio-Economic factor	Description	Level	Type
Political legislations	They encourage innovation for national agriculture activities, also boosting efficiency and competitiveness.	Local, regional, and national	Enabling
Lack of information	Difficult for all the farmers to know in time all the necessary information.	Local	Hindering
Bureaucratic process	It is difficult that a simple farmer to know how to access the possible incentives.	Regional	Hindering
Economic policy	Incentives from regional and national initiatives.	Local, regional and national	Enabling

Stakeholder needs and perceived challenges

According to various sources, including literature reviews, official reports, and stakeholder consultations, the main needs of key stakeholders regarding the uptake of RES at the farm level can be summarised as follows:

Farmers require renewable energy solutions that are economically viable and offer a reasonable return on investment. They seek technologies with manageable upfront costs and favourable payback periods. Many farmers lack technical expertise in RE systems and need access to reliable technical support and guidance throughout the installation, operation, and maintenance phases. They often face financial barriers to investing in RES and seek access to various funding options, including grants, subsidies, and low-interest loans, to offset initial investment costs. Additionally, farmers prioritise renewable energy solutions that seamlessly integrate with their existing agricultural operations without disrupting productivity or land use.

Energy communities seek opportunities to collaborate with farmers and other stakeholders to develop community-based renewable energy projects. They value partnerships that foster local ownership and benefit the broader community. Cooperatives require supportive regulatory frameworks that facilitate the development and operation of RE projects and advocate for policies that promote RES deployment and remove regulatory barriers. Like farmers, energy communities need access to financing options tailored to community-based renewable energy projects, relying on grants, loans, and crowdfunding mechanisms to finance project development and implementation.

Agricultural associations advocate for increased awareness and education on the benefits of RES adoption among farmers. They provide resources, training programs, and workshops to help farmers make informed decisions about integrating renewable energy into their operations. These associations engage in policy advocacy efforts to promote favourable policies and incentives for renewable energy adoption in the agricultural sector and collaborate with policymakers to address regulatory barriers and create a supportive policy environment.

Public authorities play a crucial role in facilitating the uptake of RES at the farm level through supportive policies, incentives, and regulations. They need to develop and implement policies that incentivise renewable energy deployment, streamline permitting processes, and provide financial support to farmers and cooperatives. Public authorities also provide technical assistance and capacity-building support to farmers and energy communities interested in adopting RES technologies. They may offer training programs, workshops, and consultancy services to help stakeholders navigate the complexities of renewable energy deployment.

Medium-sized energy industries see the agricultural sector as a potential market for RES technologies and services. They seek opportunities to collaborate with farmers and cooperatives to provide renewable energy solutions tailored to agricultural needs. Energy industries invest in research and development to innovate RES technologies suitable for agricultural applications, aiming to develop cost-effective and efficient solutions that meet the specific needs and constraints of farmers and cooperatives.

Results from Interviews

Main Takeaways: The interviews reveal a broad recognition of the importance of integrating RES into agricultural practices across different sectors. Respondents, including farmers, energy industry professionals, public authorities, and energy communities, emphasise the economic and environmental benefits of RES. They highlight the positive impact of PVs on sustainability and income, seeing PV systems as vital for providing stable income and addressing energy needs. Public authorities reflect a commitment to fostering RES integration through legislative initiatives such as those promoting biogas and agrivoltaic systems. Additionally, renewable energy communities are emerging, driven by local associations and technical partners to enhance community engagement and feasibility studies for RES projects.

Insights/Framework Conditions: Several conditions were highlighted as critical for the successful adoption of RES in agriculture. Technologically, the availability and accessibility of advanced, reliable, and easy-to-maintain RES solutions were deemed necessary. Additionally, social factors, such as community acceptance and peer influence, were noted as significant drivers, with farmers often looking to their peers for successful examples of RES implementation.

Barriers: Several barriers hinder the widespread adoption of RES in agriculture. Technological challenges, particularly the high costs and operational difficulties associated with maintaining RES installations on agricultural land, are noted. For instance, elevated PV structures pose maintenance challenges that disrupt agricultural activities. The aging farming population and a lack of knowledge about integrating RES technologies into agricultural practices are additional barriers. Furthermore, RES face issues with political incentives and access to funding, which hinder their development.

Opportunities: Despite the barriers, numerous opportunities for promoting the uptake of RES at the farm level have been identified. Developing innovative financing models, such as cooperative schemes and leasing options, can lower financial barriers for farmers. Enhancing collaboration between farmers, agricultural organisations, technology providers, and public authorities can lead to more customised and effective RES solutions, creating supportive environments for RES adoption. Technological innovations, such as vertical PV modules and agrivoltaic systems, integrate RES without compromising agricultural productivity. The growing emphasis on sustainability and climate resilience within the agricultural sector, combined with advancements making RES technologies more affordable and efficient, presents a promising opportunity for wider implementation. Lastly, educational campaigns, demonstration projects, and the role of Renewable Energy Communities (RECs) in providing information, facilitating funding access, and promoting community engagement are vital in increasing awareness and showcasing the tangible benefits of RES, thereby encouraging more farmers to make the transition.

Additional Insights: Experienced agricultural professionals emphasise the importance of sustainable practices like crop rotation to reduce greenhouse gas emissions. They advocate for the integration of RES, having implemented technologies like PV panels and wood chip-fed boilers for several years. They also emphasise the need for financial support and technological upgrades to continue benefiting from RES. From the perspective of energy communities, engaging and informing the population through meetings with technicians and specialists is crucial for leveraging opportunities and incentives.

4.3.2 *Denmark*

Overall Framework conditions

Denmark leads globally in renewable energy integration, guided by a robust national strategy aimed at achieving complete reliance on renewable sources by 2050, aligning with EU directives [124]. Wind energy stands as the cornerstone, supplying 47% of Denmark's electricity in 2022 from both onshore and offshore installations, with ongoing projects like Thor and Hesselø set to expand capacity further. Solar PV, while smaller in contribution at 3%, is growing steadily supported by government incentives [125]. Biogas and biomass also play pivotal roles, with over 150 biogas plants and biomass from wood chips contributing to reducing carbon emissions.

Challenges such as wind variability necessitate investments in grid technologies and storage solutions, while solar faces seasonal limitations despite its growth trajectory. Solar thermal energy and wave power, however, remain relatively underdeveloped due to cost constraints and integration complexities, highlighting areas for potential future growth within Denmark's diverse RES landscape [125].

Socio-economic factors

In the context of the Danish HarvRESt UC, the integration of RES such as biogas at the farm level is critical for achieving Denmark's environmental and energy targets. This section delves deeper into the socio-economic factors that influence the adoption of RES technologies by Danish farms, focusing on economic barriers and social dynamics (Table 6). These factors are pivotal in shaping the feasibility and sustainability of RES projects from a local to a national scale [126].

The level of awareness and understanding of RES technologies among farmers and the wider community significantly impacts their adoption rate. In Denmark, governmental and non-governmental organisations have launched numerous initiatives to educate the public and particularly the farming community about the benefits and operational management of RES technologies. These educational programs are crucial for overcoming scepticism and for fostering a supportive community environment [127].

Social acceptance is vital for the successful implementation of RES projects. In rural areas, where community ties are strong, the social reception of initiatives like wind farms or large biogas plants can make or break a project. Successful projects often involve early and transparent communication with the community, addressing potential concerns related to noise, smell, and changes in the landscape [128].

RES installations, particularly wind turbines, can have significant visual impacts on the landscape, which can lead to opposition from local communities who value their traditional and scenic landscapes. Addressing these aesthetic concerns through careful planning and community engagement is essential for minimising conflicts and enhancing local support [129].

The installation of RES technologies, particularly biogas digesters and solar panels, involves significant upfront costs. These costs encompass equipment, installation labour, and the necessary infrastructure modifications to accommodate new technologies. For many small to medium-sized farms, these initial expenses can be prohibitive without external financial support [126].

Financial accessibility is crucial for farm-level operators. Danish farms often rely on a combination of government grants, European Union subsidies, and local financing schemes to fund RES projects. The Danish Green Investment Fund, for example, provides tailored loans and grants that cover up to 60% of the initial investment needed for RE installations, thereby reducing the financial burden on farmers and encouraging broader adoption [125].

Denmark offers several market-based incentives to promote RES integration, including feed-in tariffs and RES certificates. Feed-in tariffs allow energy producers to sell back surplus energy to the national grid at a guaranteed price, significantly shortening the payback period of investments and improving the overall economic viability of RES projects [130].

The economic attractiveness of RES investments is largely determined by their payback periods. In Denmark, the average payback period for technologies like biogas and solar energy ranges from 5 to 15 years, depending on the scale of the project and the efficiency of the technology used. Shorter payback periods are often a decisive factor for farmers when considering the adoption of RES [126].

Table 6. Socio-economic factors affecting RES uptake at the Danish UC level

Socio-Economic factor	Description	Level	Type
Initial Investment Costs	High upfront costs for installing RES, including equipment, installation, and infrastructure.	Local, Regional	Hindering
Access to Funds	Availability of loans, grants, and subsidies to mitigate initial costs.	National	Enabling
Market Incentives	Incentives such as feed-in tariffs and RE certificates that encourage RES adoption.	National	Enabling
Payback Period	Time taken to recover investments in RES through savings and incentives.	Local, Regional	Hindering
Knowledge and Awareness	Level of understanding and familiarity with RES technologies among farmers and communities.	Local, Regional	Hindering
Social Acceptance	Community support or opposition based on the perceived benefits or disruptions caused by RES.	Local	Both
Community Support	Active community involvement and backing for RES projects, often facilitated through dialogue.	Local	Enabling
Landscape Conflicts	Opposition due to visual, noise, and other sensory impacts of RES installations on the landscape.	Local, Regional	Hindering
Aesthetic Impact	Perceived changes to the visual aspects of local and regional landscapes due to RES projects.	Local, Regional	Hindering

Legal and Political Factors

The adoption of RES on farms in Denmark is influenced by a complex interplay of legal and political factors. Denmark has implemented a range of financial incentives, including subsidies, tax breaks, and tailored grants, aimed at facilitating RES adoption (Table 7). The government's feed-in tariff scheme guarantees above-market rates for RES producers, providing a strong economic incentive [130].

The Danish legal framework supports RES integration with clear guidelines for project development, grid connection, and operation, simplifying decision-making for farmers and investors [125]. However, navigating administrative processes, environmental standards, and grid connectivity requirements across municipalities can be challenging and inconsistent [127]. Regulatory updates and legislative changes further complicate matters, affecting project timelines and costs [129].

Denmark's national energy strategy prioritises RES over fossil fuels, aligned with ambitious carbon reduction and RE targets [125]. Local governments complement these efforts with additional supports tailored to regional conditions, fostering community engagement and investment in RES projects [131].

While Denmark provides robust support for RES adoption, challenges persist due to economic barriers, regulatory complexities, and the need for coordinated policy efforts. Overcoming these challenges requires a cohesive approach integrating strong governmental support, clear regulations, effective financing, and community involvement. This holistic approach is crucial for successfully integrating RES technologies on farms, ensuring sustainable energy practices and meeting national energy objectives.

Table 7. Legal and Political factors affecting the uptake of RES at the Danish UC

Legal and political factors	Description	Level	Type
Supportive Policies	Government policies including financial incentives like subsidies, tax exemptions, and feed-in tariffs designed to reduce financial barriers and encourage RES adoption.	National	Enabling
Regulatory Clarity	Clear regulatory frameworks that provide guidelines for RES installation, grid connection, and operation, facilitating a straightforward process for farmers and investors.	National	Enabling
Complex Regulatory Procedures	Overly complex legislation and administrative procedures that can deter potential RES projects due to cumbersome permitting processes and compliance requirements.	Local, Regional	Hindering
Legislative Inconsistencies	Frequent changes in laws and subsidy schemes which can disrupt existing and future RES projects, creating a volatile environment for investors.	National	Hindering
National Energy Strategy	Comprehensive national policies that prioritise RES over fossil fuels, setting ambitious targets for RE adoption and carbon emission reductions.	National	Enabling
Regional and Local Initiatives	Local adaptations of national policies that provide additional support tailored to specific regional conditions, often including extra incentives for small-scale projects.	Regional, Local	Enabling

Stakeholder needs and perceived challenges

The adoption of RES like biogas at the farm level involves various stakeholders including farmers, energy communities, agricultural associations, public authorities, and medium-sized energy industries. Each group has distinct needs and requirements that influence their involvement and investment in biogas technologies. This analysis delves into the specific needs of these key stakeholders based on literature, official data, and other relevant sources, with a focus on enhancing the uptake of biogas within Denmark's agricultural sector.

Farmers require extensive technical support and knowledge transfer to optimise the integration and operation of biogas systems on their farms. This includes practical guidance on managing anaerobic digesters, optimizing methane yield, and maintaining equipment. Additionally, the high upfront costs associated with setting up biogas plants can be a significant barrier. Farmers benefit from subsidies, grants, and favourable loan conditions that mitigate these initial costs and provide a quicker return on investment. Incentives such as feed-in tariffs for the biogas produced also enhance the financial viability of these projects [125]. Furthermore, farmers need simplified regulatory processes that minimise bureaucratic delays and provide clarity in compliance requirements. Streamlined permitting and registration procedures would facilitate faster setup and operation of biogas facilities [127].

Energy communities, which often involve groups of farmers or local communities, require effective collaboration platforms to manage joint biogas projects, distribute profits fairly, and handle logistical aspects like feedstock supply coordination and biogas distribution [129]. These cooperatives also need established channels for accessing broader energy markets, including partnerships with regional and national energy providers to ensure the profitability of their biogas production, particularly when integrated into the national grid [128].

Agricultural associations play a crucial role in advocating on behalf of farmers and cooperatives for more supportive policies from the government. They require a strong influence on policy-making processes to secure comprehensive support packages for biogas initiatives, including enhancements to existing subsidies and incentives [130]. These associations also need access to research and development (R&D) resources to further biogas technology and improve efficiencies. This includes pilot projects that explore new techniques for feedstock optimisation, digester management, and methane capture [126].

Public authorities have a mandate to meet sustainability targets, which include significant reductions in greenhouse gas emissions. Supporting farm-level biogas projects helps achieve these goals and promotes local energy security [125]. Authorities need to facilitate community engagement initiatives that educate and garner support from local populations for biogas projects, addressing any social acceptance issues, particularly related to odour and landscape impacts [129].

Medium-sized energy industries require strategies that integrate biogas into their energy mix effectively, ensuring stability and reliability in supply. This involves technological solutions that synchronise biogas production with existing energy systems to handle fluctuations in biogas [131]. These industries also benefit from clear legislation regarding the use of biogas, including tax benefits, carbon credits, and specific guidelines that dictate how biogas can be utilised commercially [130].

The successful adoption of biogas technology in Denmark's agricultural sector requires targeted support, simplified regulations, effective collaborations, and market access. Coordinated efforts between stakeholders and supportive government policies are essential for promoting sustainable energy practices and enhancing biogas's role in Denmark's RE landscape. The Danish UC supports decision-makers with active data in decision-making processes.

Results from Interviews

Main Takeaways: The interviews with energy companies, public authorities, and farmers show a clear understanding of the factors influencing the adoption of RES at the farm level. There is a broad consensus on the critical importance of transitioning to RES to ensure sustainable agricultural practices. However, economic, regulatory, and technological challenges significantly impact this transition.

Insights/Framework Conditions: Current framework conditions vary, with some areas more ready for RES adoption than others. Energy companies call for a more supportive regulatory environment to simplify RES integration into farm operations. Public authorities acknowledge existing RE-promoting policies but admit poor implementation. Farmers show a strong willingness to adopt RES but face financial and logistical constraints. Overall, while foundational policies and technologies exist, their practical application is often inconsistent.

Perceived Barriers: High initial investment costs are the most significant deterrent, making RES financially unfeasible for many farmers. Additionally, concerns about the reliability and efficiency of RES technologies under varying climatic conditions, and the lack of tailored solutions for different types of farms, limit their effectiveness and appeal.

Opportunities: Despite these challenges, there are substantial opportunities to enhance RES uptake. The increasing awareness of climate change and the associated benefits of RE create a favourable environment for RES adoption. Technological advancements are continuously improving the efficiency and cost-effectiveness of RES, making them more attractive options for farmers. Community-based RE projects present a significant opportunity, as they can distribute the risks and benefits among multiple stakeholders. Collaborative efforts between energy companies, public authorities, and farmers can lead to innovative solutions and a more supportive ecosystem for RES on farms.

4.3.3 *Spain, VdV-VRT*

Overall Framework conditions

The EU is steadfast in its commitment to achieving Climate Neutrality by 2050, driven by the RE Directive (EU) 2023/2413, which sets ambitious targets including a 42.5% RES share by 2030 [132].

Agrivoltaics, the integration of RES production with agricultural activities, emerges as a pivotal strategy within this framework. Spain, with its abundant solar potential and extensive agricultural lands covering 23.8 million hectares, exemplifies the synergies between renewable energy generation and sustainable agriculture [133] The PNIEC outlines Spain's trajectory to increase PV capacity to 39 GWp by 2030 (Figure 14), leveraging its solar resources to foster rural development and enhance energy security [133]

Electrifying smart agricultural systems with renewable energies presents significant environmental and economic benefits. By adopting PV solar energy and integrating energy storage systems, such as batteries, these systems can substantially reduce their carbon footprint while optimising energy consumption [132]. Electric agricultural vehicles further enhance efficiency and sustainability, offering lower operating costs and reduced emissions compared to traditional diesel vehicles. Moreover, advanced charge management systems enable these systems to adapt to dynamic electricity market prices, contributing to grid stability and economic efficiency [132].

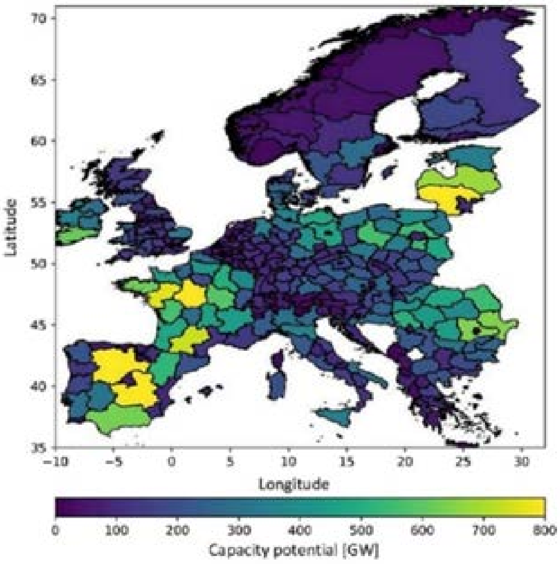

Figure 14. Maximum capacity potential for APV systems estimated for every NUTS-2 region based on the land availability and assuming a capacity density of 30 W/m^2 [133]

Socio-economic factors

The integration of RES into agricultural activities in Spain presents both economic opportunities and challenges (Table 8). Initial investments in RES infrastructure require careful consideration of financing options and return on investment, crucial for ensuring the viability and sustainability of these projects [134]. Economic benefits include energy bill savings and income generation from selling surplus energy, motivating widespread adoption among farmers [134]. However, it is imperative that these installations do not compromise agricultural productivity over the long-term necessitating robust planning and management strategies to mitigate potential impacts on land use and crop health [135].

From a broader economic perspective, integrating RES such as PV systems offers advantages like reduced grid dependency through self-consumption and additional income from grid flexibility services [136]. These benefits underscore the potential for enhancing the economic balance of agricultural operations by leveraging RES and smart technology solutions. Addressing social acceptance issues, including concerns about the impact on agricultural productivity and environmental considerations, remains crucial for promoting the widespread adoption of PVs and ensuring their long-term sustainability [136].

The conflict between agricultural land use and PV energy generation highlights the complex dynamics of balancing food production, RES expansion, and environmental preservation. With solar installations increasingly competing for fertile agricultural land due to optimal sun exposure and proximity to energy consumers, tensions arise over land allocation priorities [136]. Agrivoltaic systems emerge as a potential compromise, allowing for dual land use that supports both energy generation and agricultural productivity, thereby promoting sustainable resource management and contributing to regional food security goals.

Table 8. Socio-economic factors affecting RES uptake at the Spanish UC (VdV-VRT)

Socio-Economic factor	Description	Level	Type
Economic benefits	Key driving force for RES adoption in Spain, realised through energy bill savings or selling the generated energy. Economic benefits are crucial for the widespread adoption of RES	Local and Regional	Enabling
Land productivity and long-term planning	Concerns about the impact of RES on land productivity over the long term and the necessity of planning for the long-term sustainability of agricultural productivity, including the dismantling of solar facilities.	National	Both
Social cost of emissions	Measure negative impacts on heath, environment. Reducing the social cost of emissions can improve the image of the evaluated system.	Local, Regional, National	Enabling
Initial investment and access to financing	Challenges include initial investment costs and access to financing, which are critical for the successful adoption of RES.	National	Hindering
Return on investment	To encourage RES adoption in agriculture, it's critical to alter farmers' perceptions to appreciate short and medium-term benefits, countering the common belief that rewards are solely long-term.	National	Hindering

Socio-Economic factor	Description	Level	Type
Subsidies availability	Availability of subsidies to support RES adoption, though less emphasised compared to direct economic benefits.	National	Enabling
Reduction of environmental footprint	The environmental footprint reduction, while significant, follows economic benefits in importance for adopting RES.	National	Enabling
Permanent Structures in Agrivoltaics	Agricultural activity must also be preserved and even prioritised.	Local and Regional	Hindering
Social acceptance	Limited social acceptance of RES, particularly PVs on agricultural land, due to concerns over agricultural productivity and environmental impact. Increasing awareness and demonstrating benefits can improve acceptance.	National	Hindering

Legal and Political Factors

The implementation of agrivoltaics faces significant challenges related to defining eligible installations and regulatory frameworks across Europe, with Germany, Italy, and France leading in establishing criteria. Germany categorises agrivoltaics into elevated structures and PV installations integrated with crops, aiming for dual land use to enhance agricultural productivity and renewable energy generation [137]. Italy differentiates between basic and advanced systems, with the latter eligible for aid under national recovery plans [138], while France focuses on minimal impact on agricultural activities and sets criteria for services and income generation from agrivoltaic installations [139]

In Spain (Table 9), despite the absence of explicit agrivoltaic regulations, initiatives like Law 7/2021 [140] on climate change and energy transition and the Strategic Plan of the CAP (PEPAC) [141] aim to mitigate climate impacts and enhance energy self-sufficiency in agriculture [141]. These frameworks align with the EU Solar Strategy, encouraging multipurpose land use and promoting sustainability principles in PV integration [142]. Legislative measures such as Royal Decree 244/2019 [143] and Law 24/2013 [144]simplify administrative processes and support RE adoption among agricultural producers, fostering Spain's transition towards a decarbonised energy sector (NECP 2021-2030) [145].

The strategic alignment of European and Spanish frameworks underscores a concerted effort to enhance energy efficiency and economic resilience in rural areas through agrivoltaics and smart agricultural practices. These initiatives not only support RES deployment but also aim to attract innovative talent and promote sustainable economic growth in the agricultural sector, positioning Spain favourably in the broader European context of energy transition and climate action.

Table 9. Legal and Political factors affecting the uptake of RES at the Spanish UC (VdV-VRT)

Legal and political factors	Description	Level	Type
Evident European Interest	EU Solar Energy Strategy (REPowerEU): Encourages innovative PV deployment through multipurpose land use and suggests incentives for agrivoltaic energy in National Strategic Plans for the CAP, as well as solar energy support frameworks	European /National	Enabling
Preceding European Legislation	Germany, Italy, France: Define and categorise agrivoltaics, establishing specific criteria for implementation and access to incentives, providing a path toward clarification and support for agrivoltaics.	European /National	Enabling
Spanish Legislation	Law 7/2021 on Climate Change and Energy Transition in Spain: Incorporates measures for the integration of renewable energies into the agricultural sector, emphasising the compatibility of natural heritage conservation with the deployment of renewable energies.	Local, regional, and national	Enabling
Plan of CAP for Spain	Highlights the economic importance of the agri-food sector and promotes diversification towards renewable energies, new technologies, and bioeconomy.	National	Enabling
Absence of Specific Regulation in Spain	While potential synergies between agricultural activity and renewable energies are recognised, the lack of explicit references to Agrivoltaics in the Spanish regulatory framework may slow its adoption.	Local, regional, and national.	Hindering
Administrative and Bureaucratic Barriers	The processing of RE projects can face bureaucratic and administrative obstacles, slowing the development of agrivoltaics.	National	Hindering
Lack of Clear Definition	Uncertainty about the concept of agrivoltaics and which installations can be considered for aid complicates the planning and execution of projects.	European /National	Hindering
Legal and administrative framework from farmers view	In Spain is also perceived to be a barrier, rather than as a driver for many farmers.	National	Hindering
Agrivoltaics is not recognised	Lack of recognition of Agrivoltaics for processing, distinguishing its implementation from conventional PV systems.	National	Hindering
Legal structure governing self-	The Royal Decree 244/2019 simplifies administrative procedures, reduces costs for consumers, and establishes compensation mechanisms	National	Enabling

Legal and political factors	Description	Level	Type
consumption of electricity	for self-consumed energy that is not consumed on-site but is fed back into the grid.		
Guidelines Availability	IDAE has developed guides that support stakeholders in integrating self-consumption into their activities.	National, Regional, Local	Enabling

Stakeholder needs and perceived challenges

In the agricultural and energy sectors, various stakeholders have distinct needs and challenges that must be addressed to foster successful collaboration and implementation of RES. **Farmers** require clear value propositions that ensure positive economic returns, benefits in the short and medium term, and reduced investment risks. **Energy communities/cooperatives** must provide tailored offers that meet farmers' specific needs, along with financial and technical support, ensuring transparency in energy services. **Agricultural associations** play a crucial role in disseminating information about new technologies, offering assessment support, and facilitating networking among farmers. **Public authorities** are responsible for establishing stable regulatory frameworks, simplifying legal and administrative processes, and offering subsidies and grants to incentivise RES adoption. Meanwhile, **medium-sized energy industries** need effective communication channels to spread information about RES, collaborate with farmers' associations, and develop innovative business models for RES implementation. Additionally, these industries should provide formal studies and tools to reduce uncertainty regarding the outcomes and expected benefits. By addressing these needs and challenges, a more integrated and efficient approach to RE adoption in agriculture can be achieved.

Results from Interviews

Main Takeaways: The interviews with stakeholders from different sectors highlighted the increasing relevance of integrating RES into farming practices. Key motivations for this shift include energy security, cost savings, and compliance with national and European regulations aimed at reducing emissions. Both business associations and academic institutions recognise the necessity of a multifaceted approach involving legal, technical, and social dimensions to facilitate the uptake of RES in agriculture. A shared model of governance and direct participation from agricultural communities appear essential for successful integration.

Insights/Framework Conditions: Stakeholders emphasised the need for robust regulatory frameworks and incentives to support RES adoption. In Spain, for example, the Unión Española de Energía Fotovoltaica (UNEF) plays a crucial role by analysing regulatory barriers and connecting stakeholders. Collaboration between academic institutions and public authorities, such as the Public University of Navarre (UPNA), is vital in providing the necessary research and technical expertise. The existence of national and European directives pushing for decarbonisation in agriculture sets a favourable backdrop for these initiatives, yet practical implementation often faces hurdles.

Perceived Barriers: Several barriers hinder the widespread adoption of RES in farming. These include technological limitations, complex administrative procedures, and insufficient funding. A major challenge is the perception of PVs as a threat to agricultural productivity rather than a complementary technology. The agricultural sector often lacks the necessary information to make informed decisions about integrating RES.

Overcoming these barriers requires not only regulatory adjustments but also concerted efforts to change perceptions and increase awareness among farmers.

Opportunities: Despite the challenges, significant opportunities exist to integrate RES into farming practices. The development of pilot projects and demonstration sites can provide valuable data and practical insights, fostering wider acceptance. Creating specific programs and financial incentives for agrivoltaic systems can stimulate investment and innovation. Moreover, the evolving European regulations and the anticipated short- and medium-term incentives offer a promising landscape for increased adoption of RES. Energy communities and cooperatives can play a pivotal role in this transition by promoting local energy generation and consumption, thus enhancing both environmental stewardship and economic resilience.

4.3.4 *Spain, ACSA-Sorigué*

Overall Framework conditions

Catalonia has significant biogenic sources that can produce bioenergy, with the rural sector, particularly agriculture and livestock, playing a crucial role [146]. A strategy is needed to promote the sustainable valorisation of livestock manure and organic waste through anaerobic digestion to produce biogas and high-quality organic fertilisers [147]. This approach aims to achieve Catalonia's climate neutrality by 2050. Biogas presents a threefold opportunity: processing organic resources, reducing emissions from waste management, and generating RE, thereby reducing fossil fuel emissions.

Agriculture and animal husbandry contribute to climate change primarily through methane (CH_4) and nitrous oxide (N_2O) emissions, with some carbon dioxide (CO_2) emissions considered neutral if of biogenic origin. Methane is produced from manure decomposition under anaerobic conditions and enteric fermentation in ruminants. Non-biogenic CO_2 comes from fossil fuel consumption and nitrous oxide from microbial processes in fertilisers and ammonia (NH_3) oxidation. This represents a lost resource that also contributes to greenhouse gas effects.

Biomethane production potential from agricultural waste, animal manure, organic waste processing, and landfills in Catalonia is around 6.25 TWh [148], representing 8.9% of the natural gas consumption in this region (DACC, 2024). Anaerobic digestion of organic materials significantly reduces GHG emissions. According to EU Directives 2018/2001 (RED II) [85] and 2023/2413 (RED III) [132], high GHG emission savings per unit of energy are achieved through co-digestion of waste with livestock manure, which avoids emissions. The current strategy focuses on managing livestock excrement and organic waste to maximise biogas energy utilisation and digestate management. It identifies achievable potential, development opportunities, existing barriers, and necessary actions.

Socio-economic factors

In Spain, the economic viability of a biogas plant is determined by five main factors [149]. Firstly, biogenic sources used as raw materials play a crucial role. A consistent and stable supply of these materials is essential for efficient biogas production. According to a prospective analysis, by 2030, the quantity of materials available for biogas production is expected to be 8,908,400 tonnes. Of this, approximately 7,767,580 tonnes can be used after excluding waste destined for landfills and accounting for a 5% volume reduction during anaerobic digestion. Secondly, the specific productivity in terms of methane from these biogenic sources affects economic returns. The average income for a medium-sized biogas plant can be around €80 per MWh, and for electricity sales, the revenue can be approximately €120 per MW.

Investment and operating costs are the third key factor, varying based on the plant's size and production capacity. Typically, the investment cost ranges from €1.5 to €3 million per MWPCI BG (Megawatt Power Capacity Installed for Biogas). Operating costs include biogas production at €50 per MWh, upgrading at €20 per MWh, grid injection at €15 per MWh, and digestate processing at €10 per tonne. The fourth factor is the products obtained from the process. Commercialising digestate as fertiliser can significantly impact profitability [150]. Investment costs depend on the method of digestate transformation. In regions with nutrient excess, biogas plants need processes to concentrate nutrients for export. With an average nitrogen content of 4.98 kg N/tonne in digestate, the total nitrogen available annually is estimated at 38,682,548 kg. If this digestate could replace synthetic fertilisers, approximately 333,000 tonnes of synthetic fertilisers would not need to be produced.

The final factor is the end use of biogas, which determines its economic value. Whether used for electricity, heat, or biomethane production, the increasing demand for renewable gases in the EU adds significant economic value. To achieve profitability, biogas plants often require economic support for investments. The Government of Catalonia provides such support, and other incentives include regulated purchase prices for biomethane or electricity from biogas. Additionally, incentives involve promoting emission reduction benefits for companies producing organic waste and those consuming the energy produced. For medium-sized biogas plants processing around 25,000 tonnes annually and using manure and organic waste, with biogas valorised through cogeneration, a total investment of 1.1€ million per MWt or 2.9€ million per MWe is needed. A 35% investment support can result in an 8.5% Internal Rate of Return (IRR) over 15 years. For plants valorising biogas as biomethane, with similar processing capacity and an investment of approximately 2.7€ million per MWt, a 10% investment support is required for an 8.4% IRR over 15 years [151].

Socio-economic factors significantly affect the uptake of RES at farms in Spain (Table 10). One major challenge is the lack of information about the availability and territorial distribution of organic materials. Efforts should focus on disseminating this information to businesses and the public. Additionally, there is limited knowledge about biogas technology, administrative procedures, and financing systems. Specific outreach programs are necessary to educate stakeholders about these aspects. Furthermore, fostering collaboration between the livestock sector, waste producers, and nearby biogas facilities is essential to optimise organic waste utilisation for biogas production. Enhancing this synergy can lead to a more efficient and economically viable biogas sector, benefiting both the environment and the agricultural economy.

Table 10. Socio-economic factors affecting RES uptake at the Spanish UC (ACSA-Sorigué)

Socio-Economic factor	Description	Level	Type
Information Availability	Lack of information about the availability and territorial distribution of organic materials.	Regional/ National	Hindering
Knowledge of Technology	Limited knowledge about biogas technology, administrative procedures, and financing systems.	Sectoral	Hindering
Stakeholder Collaboration	Need for fostering collaboration between the livestock sector, waste producers, and nearby biogas facilities.	Local/ Regional	Both
Investment Support	Economic support required for biogas plant investments, including regulated purchase prices for biogas energy.	National	Both

Legal and Political Factors

The uptake of RES on farms in Spain is shaped significantly by the country's legal and political framework, emphasising biogas production and utilisation (Table 11). Key EU directives, such as RED III 2023/2413 [132] and RED II 2018/2001 [85] provide the overarching framework for promoting renewable energy, including biogas, setting integration targets across member states. At the national level, Spain has enacted laws like Law 34/1998 [152], which extends regulations for natural gas to include biogas and biomass-derived gases, facilitating their integration into the natural gas network.

Royal Decrees (RD) play a crucial role in governing various aspects of biogas infrastructure, such as RD 1434/2002 [153] for transport and distribution and RD 815/2013 [154] for industrial emissions from biogas plants. Technical guidelines and standards further support biogas integration, ensuring compliance with quality and safety measures. The sustainability of biogas production is reinforced by regulations like RD 376/2022 [155], which sets stringent criteria for biofuels and renewable gases [155].

In Catalonia, specific regulations address organic waste management critical for biogas production, complemented by laws regulating livestock and waste management practices [156]. Environmental assessment regulations ensure rigorous scrutiny of renewable energy projects under laws like Law 21/2013 [157] and Decree Law 16/2019 [158], aligning with Spain's climate and sustainability goals.

Government policies in Spain provide incentives such as feed-in tariffs, subsidies, and tax credits, crucial in stimulating farmer investment in RES. These initiatives enhance the economic viability of renewable energy projects, fostering a supportive environment for sustainable energy initiatives across the agricultural sector, and contributing to Spain's broader renewable energy targets.

Table 11. Legal and Political factors affecting the uptake of RES at the Spanish UC (ACSA-Sorigué)

Legal and political factors	Description	Level	Type
Government Policies and Incentives	Favourable policies, feed-in tariffs, subsidies, and tax credits aimed at encouraging the adoption of RES.	National	Enabling
Upfront Costs for Small Farms	High initial investment costs that hinder smaller farms from adopting RES.	National	Hindering
Legal and Administrative Complexities	Challenges faced by medium and large farms due to legal intricacies and administrative hurdles.	National	Hindering
Information Deficiency	Lack of pertinent information and offerings that deter medium and large farms from investing in RES.	National	Hindering
Unstable Regulatory Environment	Uncertain and unstable regulations that impede profitability and deter investment in RE projects.	National	Hindering
Disparities Between Farm Sizes	Variability in barriers faced by small, medium, and large farms, complicating the adoption of RES.	National	Hindering

Stakeholder needs and perceived challenges

Based on comprehensive reviews of literature, official reports, and other pertinent resources, it is evident that key stakeholders in the agricultural sector, including farmers, energy communities, agricultural associations, public authorities, and medium large-sized energy industries, have specific needs concerning the uptake of RES at the farm level in Spain. These stakeholders are primarily focused on reducing operational costs, enhancing energy security, and aligning with regulatory requirements aimed at reducing carbon emissions.

Farmers, for instance, require affordable and reliable RES technologies that can be integrated seamlessly into their existing operations. They seek systems that not only provide energy cost savings but also offer long-term sustainability and minimal disruption to their agricultural activities. **Energy communities and agricultural associations** need support in the form of knowledge sharing, funding opportunities, and technological guidance to facilitate the transition to RES. These groups often advocate for more robust support frameworks that can alleviate the financial burden of adopting new technologies.

Public authorities and medium-sized energy industries play a crucial role in creating an enabling environment for RES adoption through policies and incentives. **Public authorities** are tasked with the development of clear and favourable policies that encourage farm-level RES integration, including subsidies, tax incentives, and streamlined permitting processes. To successfully achieve the objectives of this Catalan Biogas Strategy, BETA and other technological centres will work closely with the relevant units of the Government of Catalonia as well as external stakeholders like Sorigué across the entire biogas value chain. Nearly all units of the Government involved in biogas fall under the Department of Climate Action, Food, and Rural Agenda. Meanwhile, **medium-sized energy industries** are interested in partnerships and collaborative projects that can expand their market reach and showcase the effectiveness of renewable technologies in real-world agricultural settings. Both seek to ensure that the transition to renewable energy is economically feasible and environmentally beneficial for all parties involved.

Results from Interviews

Main Takeaways: The interviews conducted with various stakeholders, including industry actors, public authorities, community organisations, and farmers, reveal a complex landscape for the adoption of RES at the farm level. Economic viability emerges as a critical factor, with stakeholders emphasising the need for clear financial incentives and affordable solutions. Regulatory support is also highlighted as a crucial enabler, with consistent policies and subsidies playing a pivotal role in decision-making. The readiness of technology and the involvement of local communities are seen as essential components for successful RES implementation. Across all interviews, there is a strong consensus on the potential of RES to enhance sustainability and reduce operational costs for farms.

Insights/Framework Conditions: The success of RES uptake at the farm level is deeply influenced by several framework conditions. A supportive regulatory environment is paramount, with stakeholders pointing to the importance of clear guidelines, long-term policies, and financial incentives. These regulatory measures can significantly boost confidence and investment in RES. Economic factors also play a crucial role; the high initial cost of RES installations necessitates the availability of grants, subsidies, and affordable financing options to make these systems more accessible to farmers. Technological infrastructure is another key consideration, as access to advanced, reliable, and user-friendly technology is essential for the smooth operation of RES. Additionally, community engagement emerges as a critical factor, with community-driven projects and cooperative models proving to be highly effective. Engaging local communities not only facilitates better acceptance of RES but also encourages collaborative investments and shared benefits.

Perceived Barriers: Despite the recognised benefits, several barriers hinder the widespread adoption of RES at the farm level. High initial costs remain a significant deterrent, as the substantial investment required for RES installations is often beyond the financial reach of many farmers. Regulatory uncertainty also poses a challenge, with inconsistent policies and a lack of long-term incentives creating an environment of unpredictability. Technical challenges further complicate adoption, particularly in remote areas where access to advanced technology and technical expertise is limited. Market dynamics, including fluctuating energy prices and market instability, can also impact the perceived benefits of RES, making farmers hesitant to invest.

Opportunities: While there are considerable barriers, several opportunities can be leveraged to promote RES uptake. Innovation in financing models, such as pay-as-you-go schemes, leasing options, and cooperative funding, can significantly reduce the financial burden on farmers and make RES more accessible. Policy reforms that introduce stable, long-term incentives, including tax benefits and subsidies, can create a more favourable environment for RES adoption. Community-based projects present another valuable opportunity, as they foster collaboration and allow for shared investments and benefits, making RES projects more feasible and attractive. Finally, continued investment in research and development is crucial for driving technological advancements that improve the efficiency and reduce the costs of RES technologies, thereby making them more accessible and appealing to farmers.

4.3.5 *Norway*

Overall Framework conditions

In Norway, as of 2022, hydroelectric power dominates electricity generation, accounting for 88% of the total output [159]. Wind power contributes 10%, thermal sources 1.6%, and the remaining 0.4% comes from various other sources. This results in approximately 98.4% of electricity generation being renewable. However, the picture changes when considering the purchase of certificates of origin [160].

In 2020, about 7 TWh of Norway's total 211 TWh energy consumption was used in agriculture, with approximately three-quarters derived from oil and oil products [161]. The Norwegian Agrarian Association aims to reduce GHG emissions in the agricultural sector by 4–6 million tons of carbon dioxide equivalents (CO_2-eq) by 2030, with 10–25% of this reduction expected from substituting fossil fuels with renewable energy sources [162].

By incorporating RE sources and electrifying energy systems, farms could reduce their carbon footprint by 44–70%, depending on the type of farm [163]. Agricultural machinery alone accounts for around 44% of the total energy consumed in farming operations [164]. Despite these benefits, the installation of RES on farms remains limited. Most installations focus on wind and solar power, with a few biogas projects mainly tied to research and innovation. These installations typically operate within the farm's microgrid and do not exceed their consumption due to administrative restrictions on feeding energy to the grid.

In 2023, Norway's farming community totalled 37,561 individuals, with 4,000 farms located in Rogaland, as reported by The Statistics of Norway. To support farmers, Norway has introduced a climate calculator as a digital tool to give farmers an overview of emissions [165]. This tool helps farmers identify opportunities to reduce emissions and sequester carbon at the farm level, promoting more sustainable agricultural practices.

Socio-economic factors

The installation of RES on farms in Norway faces significant challenges, primarily due to the absence of established support schemes tailored for agricultural settings (Table 12). Additionally, there is a lack of plug-and-play solutions that integrate RES effectively into local farm energy systems, as suppliers often specialise in specific technologies with limited knowledge of farm operations and requirements. The holistic integration of RES with farm operations remains underexplored and undeveloped.

Despite these challenges, the imperative to address climate change impacts and rising energy costs has created increased interest in locally installed RES. Such systems not only ensure reliable food production and supply but also reduce farms' vulnerability to energy market disruptions. However, stakeholder acceptance can be low due to Norway's sparse population density, with potential conflicts arising from large installations like visible wind turbines, which may disrupt landscapes and animal migration paths. Mitigating these conflicts involves ensuring stakeholders benefit from installations and addressing community concerns proactively.

Socio-economic factors influencing RES adoption on farms highlight its potential to enhance community engagement and cohesion, create new rural job opportunities, diversify income streams, optimise resource efficiency, and promote environmental stewardship. Government policies, incentives, and access to capital are pivotal in facilitating this transition, influencing farmers' decisions and project scalability. Education and awareness programs are also crucial in empowering farmers with the knowledge needed to adopt and integrate RES effectively.

The Norwegian Parliament has outlined key objectives for its agriculture policy, including ensuring food security, sustaining farming across the country, fostering increased value creation, and promoting sustainable agricultural practices. These objectives underscore the broader context within which RES adoption on farms must align, integrating economic, social, and environmental considerations into national agricultural policy frameworks.

Table 12. Socio-economic factors affecting RES uptake at the Norwegian UC

Socio-Economic factor	Description	Level	Type
Government Policies and Incentives	Norway's government plays a significant role in promoting renewable energy through subsidies, tax incentives. Policies such as the Renewable Energy Directive and the Green Energy Transition Strategy provide a framework for investment in RE infrastructure.	National	Both
Cost and Financing	The initial investment cost of RES, such as solar panels, wind turbines, or bioenergy installations, can be high. Access to financing options, grants, and favourable loan terms can significantly influence the affordability and adoption of these technologies by farms.	Local and Regional	Enabling
Resource Availability	Norway has abundant natural resources suitable for RE production, including hydroelectric power, wind energy, and biomass. The availability and accessibility of these resources vary depending on the geographical location of the farm, affecting the choice of RET.	National	Both
Technological Advancements	Advances in RET, such as improved efficiency and declining costs of solar panels and wind turbines, make these options increasingly attractive for farms.	National/Regional	Enabling
Market Dynamics	The integration of renewable energy into the broader energy market, including electricity pricing mechanisms and grid infrastructure, influences the economic viability of RE projects.	National	Enabling

Socio-Economic factor	Description	Level	Type
	Farms may participate in energy markets through mechanisms such as net metering or selling excess electricity to the grid.		
Community Engagement	Social acceptance and support from local communities play a crucial role in the deployment of RE projects. Community-based initiatives, cooperative models, and stakeholder engagement can foster greater acceptance and participation in RE development.	Regional, Local	Both
Skills and Education	The availability of skilled labour and expertise in RET can facilitate the planning, installation, and maintenance of RES on farms. Training programs and educational initiatives contribute to building the necessary capacity within the agricultural sector.	Regional, Local	Enabling
Regulatory Framework	Streamlining regulatory procedures and providing clarity on compliance requirements can accelerate project development.	National	Both
Energy Independence and Resilience	For farms, investing in RES offers the potential for greater energy independence and resilience against fluctuations in energy prices and supply.	Regional, Local	Enabling

Legal and Political Factors

Norway's energy policies prioritise renewable energy through initiatives such as the Renewable Energy Act, which establishes targets and support mechanisms like green certificates [166]. Political consensus on these goals ensures stability and encourages investment in renewable projects, although support is largely directed at specific technologies. International commitments, including the Paris Agreement, also shape Norway's renewable strategies, influencing targets and policies (Table 13).

Stakeholder engagement plays a crucial role in policy formulation, involving communities, industries, and environmental groups. While support mechanisms for RES exist for private homes, agricultural sectors like farms receive limited assistance, primarily through programs like BIONOVA, which funds bioenergy and climate initiatives. However, support excludes installations such as solar, wind, or small hydro, which vary in feasibility based on local conditions.

Moreover, national programs do not cover aspects like integrating different energy sources to match farm energy demand profiles [167]. This gap aligns with Norwegian strategies emphasising food security amidst geopolitical tensions, highlighting challenges such as grid limitations for surplus energy exports, capped at 500 kW, with associated fees often making grid integration economically unattractive [168].

Table 13. Legal and Political factors affecting the uptake of RES at the Norwegian UC

Legal and political factors	Description	Level	Type
Lack of policy coordination	The complex policy context for renewable energy, spanning multiple sectors and policy frameworks, poses coordination challenges that may hinder the uptake of RES.	Local, regional, and national.	Hindering
Lack of policy awareness	The complex policy context for RES, spanning multiple sectors and policy frameworks, and understanding its needs hinder the implementation of boundary conditions (rules, regulations, support schemes).	Local, regional, and national.	Hindering
Limitation of schemes on specific technologies	The focus on supporting and funding single technologies only leave the systems aspect out of the picture and contributes to installation of single technologies only instead of complementary ones.	Local, regional, and national.	Hindering
Financial support and incentives	Several funds and measures are available to support the adoption of RES	Local, regional, and national.	Supportive
Regulations regarding grid connection and interconnection	Regulation on grid integration and connection	Local, regional, and national.	Hindering
Electricity price in Norway	No feed in tariffs for renewable energy production	Local, regional, and national.	Hindering

Stakeholder needs and perceived challenges

Promoting the uptake of renewable energy in farms requires focusing on the diverse needs of key stakeholders through collaboration, policy support, financial incentives, and technical assistance. Farmers, energy communities, agricultural associations, public authorities, and medium-sized energy industries all play crucial roles in driving this transition.

For **farmers**, financial incentives are essential to invest in renewable energy technologies such as solar panels, wind turbines, or biomass digesters. Subsidies, grants, or tax credits can help offset the initial installation costs. Moreover, farmers often require technical support and guidance to select suitable technologies, install them correctly, and maintain them effectively. Access to affordable financing options, such as free installation, low-interest loans or leasing options, is crucial, particularly for small-scale and family-owned farms.

Energy communities rely on supportive regulatory frameworks that facilitate community-owned renewable energy projects. Clear policies, including feed-in tariffs and net metering, encourage their formation and growth. Cooperatives also need access to resources like land, technical expertise, and funding, often facilitated through collaboration with local governments, agricultural associations, and financial institutions. Effective community engagement strategies are vital to building support and participation from local residents.

Agricultural associations advocate for policies that support renewable energy integration into farms, pushing policymakers at various levels. They also provide education and training programs to increase farmers' awareness and knowledge of renewable energy benefits and sustainable practices. Facilitating partnerships and collaborations among stakeholders fosters innovation and knowledge-sharing in the agricultural sector.

Public authorities are responsible for developing and implementing policies that promote renewable energy uptake in farms. This includes creating supportive regulatory frameworks, investing in renewable energy infrastructure, and engaging with stakeholders to understand their needs and concerns. Collaboration and dialogue help build consensus and address potential challenges. Overall, addressing the diverse needs of stakeholders through collaboration and supportive policies is essential for advancing sustainable farmers' practices and promoting renewable energy uptake in Norway.

In addition, it seems to be necessary to work on building up the understanding and awareness in society for the benefits resulting from the integration of RES at farms. The current all-time availability of food in supermarkets independent from seasonal variation and location in European countries does not contribute to the awareness about the necessary effort (work and energy) for ensuring this availability.

Results from Interviews

Main Takeaways: The interviews with various stakeholders, including energy companies, public authorities, and farmers, reveal a complex landscape influencing the uptake of RES at the farm level. The stakeholders unanimously recognise the importance of transitioning to renewable energy but highlight several critical factors that impact this process. These include economic viability, regulatory frameworks, technological readiness, and community acceptance.

Insights/Framework Conditions: The current framework conditions show a mixed readiness for RES adoption on farms. Energy companies stress the need for more streamlined regulatory processes and better financial incentives to encourage farmers. Public authorities highlight existing policies aimed at promoting renewable energy but acknowledge gaps in implementation and support. Farmers are keenly aware of the environmental benefits of RES but are often deterred by the high initial investment costs and the complexity of integrating these systems into existing farm operations.

Perceived Barriers: Several barriers hinder the adoption of RES on farms. The most prominent is the high initial cost of investment, which many farmers find prohibitive. Additionally, there are concerns about the reliability and efficiency of RES technologies, especially in the harsh and variable climatic conditions typical of rural areas. Regulatory hurdles and the complexity of obtaining necessary permits are also significant obstacles. Furthermore, there is a lack of tailored solutions that meet the specific needs of different types of farms.

Opportunities: The growing awareness of climate change and the environmental benefits of renewable energy is creating a favourable environment for RES adoption. Technological advancements are making RES more efficient and cost-effective. There is also potential for developing community-based renewable energy projects that can provide shared benefits and reduce individual risks. Collaborative efforts between energy companies, public authorities, and farmers can create innovative solutions and build a more supportive ecosystem for RES on farms.

4.4 Discussion and final remarks

The investigation within Task 2.2 provides crucial insights into the socio-economic and regulatory framework conditions influencing the adoption of RES by farmers and rural communities across UC countries. This task's findings have significantly contributed to understanding the public perception and social acceptability of renewable energy projects, which is essential for designing effective awareness-raising strategies.

Our study assessed the applicability of the TAM to understand farmers' intentions to adopt RES. This research fills a notable gap, as no prior work has specifically targeted TAM scores in relation to farmers' adoption of RES. By examining key TAM constructs—perceived usefulness, perceived ease of use, and behavioural intention—we gained new insights into the unique considerations and challenges faced by farmers in adopting renewable energy technologies.

Survey results reveal that environmental stewardship is the primary driver for adopting RES in the agricultural sector. This finding aligns with the broader understanding that sustainability concerns are pivotal in shaping attitudes toward new technologies in agriculture. Our analysis confirms that TAM is a suitable framework for understanding RES adoption in this context, with PEU and PU effectively capturing the factors that influence farmers' attitudes and intentions toward RES adoption. The study also highlights the role of risk aversion, suggesting that strategies aimed at mitigating perceived risks could enhance adoption rates.

Despite the importance of environmental concerns, economic interest did not emerge as a significant driver of RES adoption intentions. This result emphasises that, even when controlling for demographic variables such as income, education, and gender, the decision to adopt RES is predominantly influenced by environmental stewardship and perceived technology attributes.

The research identified several socio-economic challenges hindering the widespread adoption of RES among farmers, including financial constraints, high initial costs, and complex permitting processes. Additionally, regulatory obstacles, such as inconsistent policy frameworks and insufficient support mechanisms, were noted as significant barriers. However, opportunities such as growing climate change awareness, technological advancements, and the potential for community-based projects offer a favourable environment for RES adoption.

To address these challenges and leverage opportunities, the successful promotion of RES in agricultural settings requires a deep understanding of stakeholder needs—farmers, energy communities, agricultural associations, and public authorities. Financial incentives, technical support, and robust regulatory frameworks are critical for overcoming barriers and fostering adoption.

Integrating the best practices identified in Task 2.1 with the insights from Task 2.2 can bridge the gap between theoretical frameworks and practical implementation. Tailoring best practices to address socio-economic challenges and regulatory frameworks, while incorporating community engagement techniques, will enhance their relevance and feasibility. Highlighting local success stories can further demonstrate the tangible benefits of RES projects, making the recommendations more actionable and sustainable.

5. CHARACTERISATION OF HARVREST USE CASES THROUGH A MULTI-ACTOR APPROACH

As outlined in the HarvRESt Grant Agreement, the **Task 2.3 focus on "Characterisation of HarvRESt use cases through a multi-actor approach"**. The objective of this task is to implement a multi-actor approach that supports the identification of the main perceptions and objectives for each use case and, in line with the KPIs initially defined in T2.4, collect the required information for the characterization of each use case.

The output has been compiled and integrated in the Deliverable 2.1 about "Mapping on RES integration in farms at EU level". The agro-community characterisation presented in this deliverable is based on an exhaustive evaluation of factors such as available natural resources, location, climatological characteristics, agricultural activities carried out and their energy demand, seasonality of demand, the level of connection or accessibility to the grid, and data monitoring and digitalization systems.

5.1 Introduction of the HarvRESt Use Cases

The full approach of HarvRESt will be supported and executed at 5 use cases located in Italy, Denmark, Spain and Norway, representing different topologies of farms, a diversity of stakeholders and organizational structures, distinct geographical conditions and a wide variety of RES technologies. Together with HarvRESt community and mapped initiatives, the project will act as a hub for knowledge and best practices on RES integration at farm level.

Italy Use Case: In this use case, main agro-industrial, farmers and industrial associations join forces to jointly address RES integration at farm level along the whole agri-food value chain, aiming to exhibit a low carbon footprint food system in large-scale trade and transferring its benefits to final consumers. The key objective is that, along the project execution, involved associations will jointly bring stakeholders to gather available information, interests and perceptions on barriers on RES integration at farm level and how it can impact or create synergies all along the food value chain and its logistics.

Denmark Use Case: The Danish use case counts with already established datasets on RES production at farm level with special focus on biogas production. In the last years, overall economic boundary conditions have been beneficial for large scale biogas plants deployment over the country, but recent developments in energy costs as well as demands arising from EU-Taxonomy/ESG makes small scale biogas plants increasingly interesting to individual or groups of farmers. Accordingly, it is expected to count with additional reports on this regard along the project execution. The main objectives are: the Biogas planning tool will be enhanced as a comprehensive database at farm level (barn/field) for Denmark; and new developments will allow the mapping of current activity level and potentials for biogas fuelled energy production, evaluating its impact on GHG-emission and nutrient balances (N and P).

Spain Use Cases: Viñas del Vero and Sorigué are two Spanish farming companies, a winery and a dairy company, respectively, at the forefront in the exploration of decarbonisation strategies and deployment of RES technologies in their farms. The key objective is to apply HarvREST solutions to enhance the production management and increase overall benefits with the lower environmental impact, as well as to produce necessary data to fill the identified knowledge gaps and deploy experimental solutions developed throughout the HarvREST community.

At Viñas del Vero effects on vineyard production through a digital based management and optimization of RES assets will be assessed. These activities will also include the electrification of machinery, thus exploring the potential in terms of cost and carbon footprint reduction of electrification. Complementarily, an experimental report on Agro-PV will take place at Viñedos del Río Tajo vineyard in Toledo, to study the impact in relation to identified KPIs to dynamically feed the HarvREst decision support system. Additionally, Sorigué's bioproducts for improving soil quality will be tested on the site.

At Sorigué the main interest is to collect data from the biorefinery to model the biogas production from agro-residues. Furthermore, the resulting by-product (the digestate) is currently considered one of the expected trade-offs. Thus, the fertilizer potential of the nutrients recovered from the digestate will be assessed in order to mitigate RES impacts, increase the circularity in the farm and diversify the farm incomes. The nutrient recovery will improve soil quality, water retention, and conservation. In addition, methane production from recycled CO_2 sources to be used as fuel itself or as an H_2 energy carrier will be analysed.

Norway Use Case: In this case GGE and NORCE will jointly analyse how to develop and expand a smart energy system that supports the full decarbonization process of GGE. A thorough analysis of the challenges for accessing the data in order to achieve centralized and optimized management of the assets composing the system will be performed. The main objective is to manage the integration of the energy storage system interaction with the different renewable assets. Moreover, the study on the coordination with farm activities will be made to optimize available resources. Given the interest of GGE on profiting manure waste for biogas production and Combined Heat and Power installation, they will also establish synergies with Sorigué's HarvREst activities as well as with the Danish use case to explore the deployment of this technology and replication of the partner's solutions.

5.1.1 *Italy Use Case*

General information

The FATTORIA SOLIDALE DEL CIRCEO is an organic farm dedicated to social and agricultural inclusion, and sustainability projects. Located in the Circeo area, the farm employs three staff members and is part of a social cooperative with about 20 members. Its mission is to integrate individuals with disabilities and those facing disadvantages into the workforce, enhancing their quality of life through personal and professional growth. The farm is expanding to include an agro-PV plant.

The Circeo area features by a **variety of soil types**, including sandy soils rich in quartz and other minerals, with good drainage properties along the coastal dunes, and clay soil in the inland area. Circeo benefits from the river Ufente, which flows through the region, providing irrigation water for agricultural fields. Additionally, there are natural springs and wells scattered throughout the area. Circeo is characterized by a diverse range of vegetation types, including Mediterranean shrubland, protected, and cultivated areas [169]. These provide important ecosystem services as well as improvements in biodiversity conservation and soil properties such as higher soil stabilization and carbon sequestration.

The farm is located near the Tyrrhenian Sea in the Lazio region of Italy, experiencing a **Mediterranean climate** with mild winters and hot, dry summers. The elevation in Circeo ranges from 0 to 100 meters above sea level, influencing local climate patterns and agricultural practices. Average temperatures range from around 10°C in winter to 30°C or higher in summer. The region enjoys abundant solar irradiation, particularly in summer, supporting crop growth. Prevailing winds from the northwest or southeast can impact crop management and soil erosion. Precipitation is moderate, mainly occurring in autumn and winter, with summers being relatively dry.

Agricultural activities

The **types of crops** cultivated in the Circeo Area are the typical of a Mediterranean area as olives, benefiting from the Mediterranean climate and fertile soil. Vegetable crops include tomatoes, eggplants, zucchinis, peppers, and other seasonal vegetables. Typical fruit crops include citrus fruits, figs, melons, and watermelons. In addition, an increasing number of farmers are adopting organic farming practices to reduce environmental impact and provide high-quality food products. Crop rotation is practiced improving soil fertility and reduce nutrient depletion, while drip irrigation systems are used to optimize water use and ensure efficient irrigation of crops.

The FATTORIA SOLIDALE DEL CIRCEO employs different types of **agricultural practices and activities**, including the use of automatic tractor seed drills and mechanical harvesting. The farm exclusively utilizes organic production methods to cultivate crops such as red lentils, fodder, zucchini, watermelon, romaine lettuce, and Romanesco broccoli, all grown in open fields. Additionally, the farm utilizes automated shower irrigation systems, which are regularly operated manually.

RES characterisation

As said above, the farm is expanding to include an agro-PV plant. The open field plant, nearing completion, occupies 110 hectares in authorized open fields, extending to 135 hectares including mitigation areas. The energy production capacity of the open field plant will be 70 MW. Additionally, within the greenhouse, a photovoltaic system has been installed covering 90 m^2 out of a total area of 180 m^2, with an energy production capacity of 5 kW.

Currently, the approximate **energy usage of the farm** stands at about 20 kW and it is sourced from a combination of photovoltaics and the national grid. This consumption is anticipated to change soon potentially increasing the energy usage to over 100 kW, due to plans to install an electric irrigation system and additional equipment. The electricity grids are internal to the company, so no connections must be made, and no distance must be taken from the production area. Also, no storage systems are used. The highest consumption peaks are detected during the summer period due to a sharp increase in irrigation supply.

Regarding **data monitoring**, currently the farm can share various types of data, including demand data, PV generation data, and agricultural production data. Data collection is facilitated by automated sensors, monitoring crucial parameters such as light, temperature/humidity, and CO_2. Real-time energy monitoring is available through the inverter, but monitoring environmental conditions and crop health requires further development. Additionally, there is no integration of collected data into decision-making processes and farm management systems. The digital infrastructure for data storage and analysis consists mainly of a laptop. Common challenges in data collection and digitization include issues with connectivity and accuracy. However, the company has defined future plans to cover needs for upgrading the digital and monitoring infrastructure, indicating a commitment to improving and adapting to emerging needs.

Expected Outcomes

In this section, we present the anticipated outcomes that may be developed in the Italian Use Case along with their potential alignment with Key Exploitable Results (KERs). While the specific Key Performance Indicators (KPIs) are yet to be precisely defined, this outline serves as a preliminary framework that will evolve as the project progresses and as the feasibility of various experiences becomes clearer.

EO New business model

- <u>Description</u>: Currently, reduced carbon footprint agricultural productions are not recognized as an added value in the value chain. Thus, the objective is to explore new business models to increase the interest of food industry and large-scale distribution stakeholders in agricultural products with reduced carbon footprint. In addition, the new approaches to valorise "farmers social impact" will be also investigated.

- Expected Outcome: Creating a new business model by: exploring new certification models to exploit the environmental and social impacts of agricultural productions, also in relation to the requirements of ESG regulation; understanding how RES can generate added value, not only in product sales but also in promoting the concept of sustainability through initiatives as example Carbon Credits; and also promoting the replicability of virtuous models in the agrivoltaics sectors.
- Associated Key Exploitable Results (KERs):
    - KER8. HarvRESt AVPP
    - KER9. HarvRESt DSS
    - KER10. Strategy for multiactor engagement
    - KER12. BM catalogue
- Some Tentative KPIs to Consider:
    - Set of KPIs related to the Performance of assets
    - Improvement of economic impact of agricultural production
    - Improvement of social impact of agricultural production
    - Improvement in the sustainability of agricultural practices

5.1.2 *Denmark Use Case*

General information

The agro-community is located in Denmark, with the **key stakeholders** being farmers, agricultural organizations, biogas companies, organic producers, and regulatory bodies. The country encompasses a total land area of 4,309,000 hectares, with 2,669,356 hectares dedicated to agriculture (approximately 62% of the total land) and 277,000 hectares organically farmed [170]. It has a population of 6 million inhabitants and is characterized by its predominantly flat topography, with no mountainous regions.

In the **agricultural landscape**, sandy loam soils predominate, covering approximately 1,447,181 hectares. Another significant portion includes clay-enriched soils, amounting to about 1,063,557 hectares; and organogenic soils, rich in organic matter, that are prevalent in peat bogs and former wetlands. The unique hydrography of this country includes no significant rivers but a dense network of streams and minor rivers that drain into surrounding seas. The country relies heavily on groundwater, sourced from its 600,000-plus wells, for both drinking and irrigation purposes. Groundwater extraction, however, is meticulously managed to prevent depletion and ensure long-term availability, reflecting Denmark's proactive environmental stewardship. Approximately 14.5% of Denmark is forested, with significant efforts geared towards sustainable forest management. The country's forestry practices are designed to balance production needs with environmental conservation. The state and private owners manage these forest lands to produce timber, protect biodiversity, and provide recreational spaces for public use.

Denmark's climate is influenced by its proximity to the sea, which brings moderate levels of precipitation distributed fairly evenly throughout the year. The country receives an average rainfall of about 800 mm annually, but this can vary regionally. Humidity levels are generally high, which can affect agricultural decisions, particularly in relation to irrigation and crop selection. Being a flat country near the North Sea and Baltic Sea, Denmark is subjected to considerable wind activity. Wind speeds vary across the year but are generally higher during the winter months. This has facilitated the development of a robust wind energy sector in Denmark.

Agricultural activities

Denmark's **agricultural framework** supports a substantial livestock sector, with an emphasis on pig production, predominantly for meat, dairy and beef cattle, for both milk and meat production, and poultry, including both egg-laying and meat production birds. The agricultural sector is notable for its significant pig production, totalling 12,495,132 pigs in 2023, which generates high volumes of liquid manure. This manure is primarily managed through biogas production or direct use as fertilizer. Denmark is a global leader in the development and production of equipment for managing animal manure as fertilizer, underpinning the robust biogas production sector within the country.

The agricultural landscape is divided into **several soil types**, predominantly sandy loam, which facilitates easy cultivation and efficient drainage. Other types present are: clay-enriched soils, beneficial for their moisture and nutrient retention capabilities which are crucial during the drier periods; and organogenic soils, rich in organic matter, that are especially fertile and support a diverse array of crop types.

In 2023, Danish agriculture utilized a total of 2,669,356 hectares for various crops, reflecting a **diverse agronomic base**. The cultivation can be broken down into different categories like grain, maize, oilseeds, fruit, vegetables, etc. Generally, Danish farmers make use of advanced agronomic practices like precision farming utilizing GPS and IoT technology to enhance efficiency, integrated pest management (IPM) employing a combination of biological, cultural, and chemical practices to control pests sustainably and crop rotation and soil management, fundamental practices that help maintain soil health and fertility.

RES characterisation

In Denmark, the agricultural sector is a crucial part of the national economy and consumes substantial energy due to the mechanization and modernization of its practices. The **total energy consumption** in Danish agriculture is approximately 1.7 petajoules in 2020, representing about 1.5% of the country's total energy use [170]. Main sources of energy consumption in agriculture are heating, used for greenhouses, livestock barns, processing facilities, crop harvesting, irrigation systems, ventilation systems, and milking machines.

The **energy demand** in Danish agriculture exhibits significant seasonal variations, which reflect the cyclical nature of farming activities. These variations are influenced by climatic conditions, crop cycles, and livestock needs. Energy demand increases in spring with the start of the sowing season and peaks in summer during dry spells when irrigation systems are heavily used. The energy use also spikes for ventilation systems in livestock barns to mitigate heat stress in animals. During autumn high demand continues as crop harvesting is underway and finally in winter energy demand decreases but remains significant, particularly for heating greenhouses and livestock barns. The main energy sources used are electricity from the grid for all forms of mechanized equipment, fossil fuels like diesel for mobile machinery, and natural gas for heating purposes, renewable energies like biomass for heating, wind power and solar for on-site electricity.

Danish farms generally boast **excellent connectivity** to the electrical grid, and most farms are less than 1 km away from a grid connection, facilitating straightforward access to grid electricity. Denmark's shift towards renewable energies is mirrored in its agricultural sector. Many farms are within 10 km of a wind farm, providing potential synergies for direct power supplies and energy trading. It is common for farms to integrate their operations with biogas production, either through onsite facilities or proximity to such plants [171]. Backup power sources are vital in ensuring continuous operation, particularly to counteract grid instabilities. Diesel generators are commonly available on farms to ensure uninterrupted power for critical operations like dairy farming. The adoption of battery storage systems is on the rise, especially to store excess power from solar panels or to help stabilize grid voltage.

Rather than monitoring ongoing biogas production processes and data, the Danish use case is distinctively structured around a **decision-support system** aimed at evaluating the potential for biomass utilization in the biogas industry. This strategic approach emphasizes the analysis of potential capabilities across various scales of biogas operations, from individual farm-level setups to larger community-based or commercial facilities. Importantly, the decision-making process within this use case does not necessitate real-time data since it focuses on potential assessments rather than the real-time operational monitoring of biogas plants. The data utilized primarily stems from consecutively updated records maintained by farmers and regulatory authorities. This includes comprehensive information sourced from publicly available databases which provide sufficient detail to evaluate long-term potential rather than immediate production metrics. By not relying on real-time data or direct sensor inputs for data acquisition, the system can effectively conduct extensive potential analyses without the need for instantaneous data flow. This methodological choice aligns with the goal of maximizing strategic planning over operational surveillance, catering to the developmental and expansion prospects within the biogas sector. This framework allows for a broad-based evaluation of biogas potentials, facilitating informed decision-making that can scale across different sizes and types of biogas plants.

Expected Outcomes

In this section, we present the anticipated outcomes that may be developed in the Danish Use Case along with their potential alignment with KERs. While the specific Key Performance Indicators (KPIs) are yet to be precisely defined, this outline serves as a preliminary framework that will evolve as the project progresses and as the feasibility of various experiences becomes clearer.

EO Enhanced Biogas Planning Tool, Economic and Environmental Benefits, Innovative Business Models, and Scalability and Policy Recommendations

- Description: This use case focuses on leveraging existing datasets to increase the implementation of small to medium-sized biogas plants, enhancing energy self-sufficiency and sustainability in agriculture. Thus, the main objective is to develop a comprehensive biogas planning tool for optimizing manure-based biogas production at bigger biogas plants supplied from farms in Denmark.
- Expected Outcomes:
  - Enhanced Biogas Planning Tool: Development of a comprehensive, farm-level database for optimizing biogas production, including economic and environmental impact assessments.
  - Economic and Environmental Benefits: Obtainment of demonstrable economic benefits for farmers and significant reductions in greenhouse gas emissions and improved nutrient management.
  - Innovative Business Models: Development of actionable, innovative business models utilizing big data to maximize manure's value for nutrient recovery and energy production.
  - Scalability and Policy Recommendations: Creation of a guidelines for replication across the EU, addressing data regulatory barriers and promoting sustainable agricultural practices.
- Associated Key Exploitable Results (KERs):
  - KER4. Biogas planning tool
  - KER5. Forecasting algorithms
  - KER7. HarvRESt smart energy system algorithms

- KER8. HarvRESt AVPP
- KER9. HarvRESt DSS
- KER12. BM catalogue
- KER13. Co-creation guidelines

- Some Tentative KPIs to Consider:
  - Set of KPIs related to the Performance of assets
  - Optimization of biogas production
  - Improvement in economic impact
  - Reduction in GHG emissions
  - Improvements in nutrient recovery and management

5.1.3 *Spain Use Case (VdV-VRT)*

General information

This use case is developed in Viñas del Vero (Somontano, Huesca) and Viñedos del Río Tajo (Guadamur, Toledo).

Viñas del Vero is part of the Somontano DO established in 1984, and it is located in Huesca province (Aragon), around the city of Barbastro, at the foot of the Pyrenees. The Somontano region has a population of 25,000 people and features ideal altitudes, climate, and soils for vine growing. Somontano features distinct agro-climatic and orographic units; the outer sierras of the Pre-Pyrenees with notable canyons and gorges, a transition zone with predominant woody crops and cereals and steppe-like plains with hills and valleys, specializing in cereals and extensive livestock farming. Viñas del Vero soils are typically poor, stony, and limestone-rich. The altitude of the terrain ranges from 300 m to 1500 m. It is characterized by a Mediterranean climate with continental influences that include hot, dry summers and mild, wet winters. The region experiences a significant temperature range between seasons. Precipitation is more common in the autumn and spring months, while summers are generally dry with an average annual rainfall of 500 mm.

Viñedos del Río Tajo was established in 2014 and consists of two estates, Daramezas and Bergonza, in Toledo province (Castilla-La Mancha), comprising 430 hectares of vineyard in total. Located in Guadamur (population: 1,800 people) in the Montes de Toledo region, the Daramezas estate is bordered by the Tajo River to the north. It is in an area of mountains, valleys and streams that give shelter to a flora where you can find Mediterranean oak forests, pastures and cultivated fields. At Viñedos del Rio Tajo the highest point in the municipality of Guadamur is at La Condesa, at 687 m above sea level. This terrain is also characterized by a Mediterranean climate with continental influences.

Agricultural activities

Regarding **Viñas del Vero**, in Barbastro area pink tomatoes, cereals, vegetables and vines are the main crops. Focusing in the wine sector, the Somontano DO encompasses 29 wineries and 4,000 hectares, cultivating 15 grape varieties. Viñas del Vero owns 515 hectares of vineyards and controls an additional 500 hectares. Almost half of the industries in Somontano are dedicated to the agri-food sector (23%) and to the manufacture of beverages (20%).

Viñedos del Río Tajo consists of two 430-hectare estates designed for highly mechanized cultivation to produce high yields of grapes for quality Brandy distillation. In the case of Guadamur (Viñedos del Rio Tajo), the primary activities in the area revolve around cereal cultivation and livestock farming.

RES characterization

In both places, there is a higher **electricity consumption** profile from Monday to Friday within the week. Throughout the year, the months with the highest energy demand are from July to October.

Viñas del Vero's total electricity consumption is 1,413,164 kWh/year. Of this, 1,028,050 kWh per year are sourced from the external network, and 385,114 kWh per year are self-generated and consumed from installed photovoltaic systems. It also consumes a total of 2,675 L of diesel and 12,204 kg of propane. The transformation centre is located in the winery itself and there are no renewable facilities nearby. Regarding the daily generation and consumption profile in Viñas del Vero there is greater coverage of demand during the central hours of the day (coinciding with solar photovoltaic generation), which can lead to the generation of surpluses to be injected into the grid.

In the case of **Viñedos del rio Tajo**, total electricity consumption is around 939,000 kWh/year. Consumption is split between two estates, Daramezas and Bergonza, with Daramezas having a self-consumption ratio of approximately 10%.

The **data monitoring and digitalization** of this use case is focused in different ways on the two areas: monitoring an agrivoltaic (Agro-PV) pilot plant and the effects of the partial vines shadowing on grape quality and crop growth and health at Viñedos del Rio Tajo, and establishing an efficient energy management system at Viñas del Vero.

For data monitoring in **Viñedos del Rio Tajo**, IoT technology is used to continuously monitor vineyards, collecting climate, plant, and soil data, which are analysed for optimizing the position of solar panels, prioritising the vine physiology above the PV energy production. Additional digital tools and technologies include drones, satellite images, sensors, alarms, deductive programs, and irrigation automation. Vigour maps are used to adjust the dosage of phytosanitary products, applying lower doses in areas with low vigour and higher doses in areas with greater vigour. Treatment machines are finely tuned, with instantaneous speed control and liquid dose control to prevent active substances from being lost due to wind.

For energy management in **Viñas del Vero**, the winery uses meters, energy storage systems, and a SCADA-type system to optimize machinery operation times. The winery employs control and automation in the operation of air compressors, cold needs for fermentation processes, and sensors to reuse fermentation gases. Automated control of fermentation temperatures is crucial for the quality and organoleptic profile of the final product, the wine. The project aims to enhance this system by incorporating grid price considerations and integrating more electrified consumption, such as electric tractor. Additionally, the HarvRESt project will further expand and improve this setup, aiming to develop integrated energy management and electrify parts of the production chain that currently rely on fossil fuels.

Expected Outcomes

In this section, we present the anticipated outcomes that may be developed in the Viñas del Vero & Viñedos del Tajo use case, along with their potential alignment with KERs. While the specific KPIs are yet to be precisely defined, this outline serves as a preliminary framework that will evolve as the project progresses and as the feasibility of various experiences becomes clearer.

Viñas del Vero: development of a global energy management platform

- Description: This experience involves creating a comprehensive energy management platform for Viñas del Vero. The platform will integrate and manage the photovoltaic (PV) production, energy storage, and grid demand for the winery. The platform will also focus on studying the market behaviour and energy needs to maximize renewable energy consumption and minimize dependence on grid energy. In the vineyard, the experience will include the integration and reliability assessment of an electric tractor, optimizing its consumption, autonomy, and adaptation to different implements.
- Expected Outcomes: Enhanced energy efficiency increased self-consumption of renewable energy, and optimized operation of electric agricultural machinery.
- Associated Key Exploitable Results (KERs):
  - KER2. KPI's for Performance Monitoring
  - KER5. Forecasting Algorithms
  - KER7. HarvRESt Smart Energy System Algorithms
  - KER8. HarvRESt AVPP
  - KER9. HarvRESt DSS
- Some Tentative KPIs to Consider:
  - Set of KPIs related to the Performance of assets
  - Solar Generation Performance
  - Self-consumption ratio of renewable energy
  - Battery Storage Efficiency
  - Specific Energy Consumption per Equipment
  - Reduction in grid energy dependence/Grid Energy Performance
  - Reduction in GHG emissions
  - Operational efficiency of the electric tractor. Energy consumption per hour of tractor operation.

Viñedos del Rio Tajo: development of a study on the influence of solar radiation on crops in agrivoltaic environments

- Description: This experience focuses on conducting a comprehensive study to analyse the influence of solar radiation on crop behaviour within agrivoltaic systems. The study can involve the development of an algorithm, processing of sensor data, and continuous monitoring of plant vegetative processes. The objective is to optimize growing conditions and improve the sustainability and productivity of the vineyard under the unique conditions provided by agrivoltaic installations.
- Expected Outcome: Enhanced understanding of how solar radiation and partial shadowing affects crop growth in agrivoltaic systems, leading to optimized agricultural practices and improved crop yields and quality.
- Associated Key Exploitable Results (KERs):
  - KER2. KPI's for Performance Monitoring
  - KER8. HarvRESt AVPP
  - KER9. HarvRESt DSS
- Some Tentative KPIs to Consider:
  - Crop yield and quality metrics under the agrivoltaic system:
    - Bunch size and weight, number of bunches per vine
    - Grape kg/vine and grape kg/ha

    - Grape quality: total acidity, pH and sugar content (ºBrix)
    - Leaf Area Index and SA (vegetation growth)
  - Vine physiology metrics under the agrivoltaic system:
    - Trunk diameter variation (dendrometry)
    - Steam water potential and photosynthesis rate
  - KPIs regarding to microclimate generated by the interaction of solar panels with the vines:
    - RH, temperature and solar radiation in vines shadowed by solar panels VS not shadowed vines
    - Irrigation water consumption by shadowed vines VS not shadowed plants (it is expected to reduce the evapotranspiration with Agro-PV, and therefore the irrigation needs).

5.1.4 *Spain Use Case (ACSA-Sorigué)*

General information

Sorigué-Torre Santamaria is a partnership mainly dedicated to the agro-technology provider and the cow's farm in Noguera Region (Balaguer, Catalonia). This region has a population of 38,770 people (in 2019) and a surface of 1,784 km^2. In the area of influence of Sorigué, there are livestock farms managing over 25,000 cows and also pig and chicken farms, covering an irrigated area of 70,000 hectares.

In 2011, the Torre Santamaria farm installed one of the first **biogas plants (digesters) capable of decomposing the manure** generated by the cows and transforming it into gas to meet the farm's heating and hot water needs, being (by 2021) the first farm in Spain to inject biomethane into the grid. Sorigué currently processes 30,000 tonnes/year of livestock waste +20,000 tonnes/year of agri-food waste at its plant. In the near future, it aims to expand its biomethane plant to manage 300,000 tonnes of livestock waste, thereby providing waste management services to farms in the surrounding municipalities.

In Balaguer, the **soils** generally have silty-loam texture, being quite deeps and with good drainage [172]. The north part of Noguera is dominated by mountainous terrain and the south one coincides with the plain. The major rivers drain north to south cutting perpendicularly through the Pre-Pyrenees ranges, forming narrow gorges. These gorges have been used to construct reservoirs shaping areas with rich and varied fauna and flora. The Noguera has a continental **Mediterranean climate** which is characterized by cold winters and hot summers, with a significant temperature range between seasons. Precipitation is moderate, typically concentrated in the spring and autumn, while summers tend to be dry.

Agricultural activities

Around the farm there are more than 500 hectares of corn planted to feed the cows and nearby (about 5 km) more than 400 hectares of almond trees, fruit trees, olive trees and cereals planted. These fields are irrigated with water from the canal d'Urgell. Noguera is the largest agricultural region in Catalonia, there are 64,000 hectares of agricultural area and 2,141 hectares of ecological agriculture [173]. Surrounding the farm, the **main crops for animal feed** in the area are:

- Branch alfalfa or alfalfa hay: an essential food for animals due to its high content of fibre, minerals, calcium, organic phosphorus, vitamins (A, B1, B12, C, D, E, and K), and especially protein.
- Straw: despite its low nutritional value, can constitute a high proportion of the maintenance diets in extensive livestock farming, as it satisfies the animals' appetite and keeps them feeling full.

- Corn cultivation: it is the main crop in the Canal d'Urgell area, and it has shown a significant increase in recent years being the main substrate in livestock feed through the production of feed and silage.

RES characterization

For Torre Santamaria (with more than 2,000 cows), the **energy consumption** is more than 1,000,000 kWh. Average electricity consumption stands at 516 kWh per productive cow and year or 51 kWh per 1000 kg of milk produced per year being the vacuum pump the most consumptive equipment (8,948 kWh/year), the cooling tank (6,030 kWh/year) and the cleaning systems. Energy consumption on the farm varies between summer and winter. In winter, more energy may be used for heating, preventing water from freezing, and increased lighting due to shorter daylight hours. In summer, cooling systems for the animals and milk storage can lead to higher electricity use.

For the current **waste management plant (biomethane plant)**, the total energy consumption is 4,616,840 kWh/year. It has a self-consumption rate of 38% thanks to the cogeneration system but currently, this system is not working due to the whole biomethane production being injected directly into the natural gas network. Therefore, all the energy consumed in the farm and in the biomethane plant comes from the electrical grid. More energy is required in winter to heat the digesters to the mesophilic temperature range (37-40°C). In winter, energy equivalent to 20% of the produced biogas (800,000 Nm^3 of biogas per year) is used to feed the boiler, whereas in summer, only 10% is used. There is no demand peak times as the production of the farm and the waste treatment plant remains constant. As a backup, the farm and the waste management plant always use diesel generators. To distribute the 50,000 tons of digestate treated at the biogas plant in the fields around 250 m^3 of diesel are used.

The SCADA system forms the backbone of the **data monitoring and control** as it enables real-time monitoring and control of the process within the plant, providing essential insights into operational performance. Some of the processes that the system can automate currently are the adjustment of liquid or gas levels, the transfer of biogas from digesters to the upgrading unit and the regulation and establishment of injection flows into the network. Besides all the information provided by the SCADA, certain measurements are conducted manually. This includes the daily measurement of pH, temperature, and conductivity in the digestate performed with multiparametric probe. Furthermore, the biogas composition in the digesters including methane, CO_2, O_2, CO H_2S and VOCs are monitored using a measuring device from Sewering and Drager, respectively, at different points in the upgrading unit.

Regarding the farm, each cow is equipped with a pedometer to monitor its activity level (estrus, resting, etc.) and they also have a geolocation sensor integrated into their leg. Additionally, the milk production of each cow is monitored using flow meters on each milking machine. All this information is compiled into an Excel spreadsheet for data control.

Expected Outcomes

In this section, we present the anticipated outcomes that may be developed in the ACSA-Sorigué Use Case along with their potential alignment with Key Exploitable Results (KERs). While the specific Key Performance Indicators (KPIs) are yet to be precisely defined, this outline serves as a preliminary framework that will evolve as the project progresses and as the feasibility of various experiences becomes clearer.

EO Improvements in data collection, nutrient recovery and circularity, and new methane production pathways

- Description: In this use case, the main problem is the management of the digestate and the optimization of the anaerobic digestion. Thus, the objective is to improve the valorisation of the digestate and to study the production of synthetic biomethane mixing this side stream with H_2 produced by electrolysis of recovered water from farm activities.
- Expected Outcomes:
  - To collect data from the biorefinery to model the biogas production from agro-residues.
  - To assess the fertilizer potential of the nutrients recovered from the digestate (the resulting by-product), which is currently considered one of the expected trade-offs, in order to mitigate RES impacts, increase the circularity in the farm and diversify the farm incomes. The nutrient recovery will improve soil quality, water retention, and conservation.
  - To analyse the methane production from recycled CO_2 sources to be used as fuel itself or as an H_2 energy carrier (This will be done theoretically, since there is no plan to create any methanation prototype).
- Associated Key Exploitable Results (KERs):
  - KER2. KPI's for Performance Monitoring
  - KER3. Soil quality methodology
  - KER4. Biogas planning tool
  - KER8. HarvREStAVPP
  - KER9. HarvREStDSS
- Some Tentative KPIs to Consider:
  - Set of KPIs related to the Performance of assets
  - Optimization of biogas production
  - Improvements in nutrient recovery and management
  - Improvements in soil health

5.1.5 *Norway Use Case*

General information

The Norwegian use case is the **farm Røysland Gaard**, in the project represented by Grønn Gardsenegi, both having the same owner. The farm is located close the southwest coast of Norway at 58.654° north latitude and 5.948 ° eastern length and at an elevation of 236 m above sea level. The farm covers a total area of 2,200,000 m^2, and there are 2 people living permanently. The farm and the integrated butcher provide high quality meat to star restaurants and hotels in the areas of Stavanger, Bergen Kristiansand and Oslo. Currently it is in the process of being developed towards a 100% energy independent farm utilizing local RES.

The **types of soil** are as follows: 37,000 m^2 fully cultivate and now used to grow grass food for the animals, 100,000 m^2 of un-cultivated grassland, 1,000,000 m^2 of grassland with trees, and 600,000 m^2 with wood. The rest is covered with water (creeks, lakes and ponds) as well as rocky mountain. On the area there are two lakes separated by a dam and with a difference in height of the water surface of up to two meters. This is expected to allow for 11kW hydropower delivering 62,000 kWh/year of electricity. A small creek running down the mountain behind the farm buildings and fed from a small intermediate reservoir plus a 20 kW hydro turbine allows for about 74,000 kwh/year. Both hydro plants are not yet in operation but in the planning phase. The local vegetation consists of grass as well as natural and planted forest. Birch and aspen are naturally growing while pine trees were planted. Local availability of mineral deposits is unknown and was never evaluated as being not relevant for the operation of the farm.

The farm is located about 250 m above sea level. This area experiences a **temperate oceanic climate**, characterized by mild winters, cool summers, and high levels of precipitation throughout the year. The proximity to the coast and the elevation influences the local climate, contributing to relatively moderate temperatures and consistent rainfall.

Agricultural activities

As indicated above there are no crops grown on farm which focusses on **livestock only**. There are in a yearly average 20 cattle (Wagyu) on the farm as well as 175 pigs. The cattle are grown on the farm, with about 50% local and 50% from Japan (embryos). The pigs are purchased at a weight of about 70 kg and grown on the farm up to weight of about 115 -130 kg. Both are outgoing as they want (i.e. no fixed times in the stables). They are predominantly fed with locally available and grown food and a low amount of purchased power furrow.

RES characterisation

In the farm, a new stable is in preparation, prepared for biogas option and extracting / using methane in the ventilation air. There is already PV installed on the roof (52.56 kWp) and a battery storage (136 kW). In the slaughter is a heat storage of 20 m^3 installed to recover heat from 5 cooling machines. The heat is used to contribute to providing hot water for the slaughter.

The **total energy consumption** is 400,000 kWh/year of electricity from the grid and an additional 46,620 kWh from local PV panel production (2023). The primary energy consumption is for the butchery's heating, cooling, cleaning, and tool operation, followed by farm operations and building energy use. Given the operation of the farm (growing cattle and pigs) is the energy usage pattern well balanced during the year with relatively low variation of due to seasonal impact. Off-peak demand periods are to be covered by the battery pack and the control system which targets an optimisation towards energy costs (i.e. minimisation). Factors influencing weekly and seasonal energy demand fluctuations are, for instance, start-up of the equipment, usually on Mondays or after vacation, although there no major variations.

The nearest **power grid connection point** is located on the farm, with a farm-owned transformer ensuring high reliability of the grid infrastructure, with no disconnections in recent years. A renewable generation plant consisting of large wind turbines, located about 200 meters from the farm buildings on the farm's premises but owned and operated by a third party, feeds energy directly into the grid without connecting to the farm's energy system. Backup power integrated in the microgrid of the farm is available through a 136 kW battery pack, providing power for one hour. Fossil fuels are used for the tractor, an excavator on the farm, and three diesel-fuelled cars for the butchery. There are also two electric cars, one for the farm and one for the butchery.

Regarding **data monitoring**, currently, data available from the farm for sharing includes demand data, PV generation and battery capacity. Data collection methods will involve automatic data collection via the Eco Store AS system, the battery supplier, although the old pack was damaged due to flooding. A new higher-capacity battery pack will be installed in May 2024. Additionally, an automation system from KE Automasjon is planned as part of the project. Sensors deployed include those measuring ambient temperature, soil temperature, humidity, energy consumption, and PV generation. As the farm focusses on livestock only are parameters like soil moisture and soil agrochemical parameters not monitored. IoT devices currently control the EMS to manage the battery and reduce energy costs. Digital infrastructure for data storage and analysis is based on cloud services accessible via the supplier's app, but the new system will store data locally. Digital platforms for data visualization and analysis are provided by PV and battery suppliers. There is no additional level of automation in data collection and reporting processes beyond what is accessible via the supplier's app, but this might change with the new automation system.

Expected Outcomes

In this section, we present the anticipated outcomes that may be developed in the Norwegian Use Case along with their potential alignment with KERs. While the specific KPIs are yet to be precisely defined, this outline serves as a preliminary framework that will evolve as the project progresses and as the feasibility of various experiences becomes clearer.

EO Energy systems planning tool, Energy management tool, Economic and Environmental Benefits, Innovative Business Models, and Scalability and Policy Recommendations

- Description: This use case focuses on the utilisation of locally available potential of renewable energy sources, security of energy and therefore food supply and become independent from the distribution grid or even allow feeding energy into it. The main objective is to develop a conceptual and operational optimisation of an energy system on a farm considering various locally available energy sources to securely cover the energy needs as well as form a base for disseminating and exploiting the concept in Norway.
- Expected Outcomes:
    - Energy systems planning tool: to allow developing energy systems concepts for the pilot farm as well as follower farms (maybe "islands").
    - Energy management tool: to allow for an efficient and economic operation of the integrated energy system on the farm with the aim of being energy independent.
    - Economic and Environmental Benefits: Demonstrable the concept thus paving the way for further replication and dissemination. On the farm level it will in the long run reduce the energy costs, on a societal level it will contribute to a secured food supply thus reducing the dependence on import (transport related emissions, etc.).
    - Innovative Business Models: Development an innovative business model making it attractive for others to replicate the concept.
    - Scalability and Policy Recommendations: Guidelines for replication in Norway (not an official EU member), addressing regulatory barriers and promoting sustainable agricultural practices and a secured food supply.
- Associated Key Exploitable Results (KERs):
    - KER7. HarvREStsmart energy system algorithms
    - KER8. HarvRESt AVPP
    - KER9. HarvRESt DSS
    - KER12. BM catalogue
    - KER13. Co-creation guidelines
- Some Tentative KPIs to Consider:
    - Set of KPIs related to the Performance of assets
    - Optimization of energy production
    - Optimization of energy costs
    - Reduction in environmental impact
    - Improvement in the sustainability of agricultural practices

6. CONCLUSIONS AND NEXT STEPS

In conclusion, the integration of renewable energy sources within agriculture is essential for addressing environmental societal and economic challenges. At the farm level, RES can enhance agriculture productivity, reduce greenhouse gas emissions, and improve sustainability, while also optimizing energy use and lowering costs. However, this transition is not without challenges, such as potential biodiversity loss due to land use changes. Therefore, a comprehensive approach that considers climate, land, energy, and biodiversity and food security is critical for successful integration.

Stakeholder engagement is paramount for optimal integration. Involving farmers, local communities, policymakers, and industry partners can lead to better RES integration through innovative business models and cooperative financing mechanisms that promote resilience and shared benefits. Furthermore, understanding key factors such as thorough site planning, energy storage availability, and robust management systems is crucial. As the agricultural sector navigates the complexities of integrating renewable energy, education and training will be vital for maximizing the potential of these systems.

Moving forward, the information gathered in Task 2.1 and the table with relevant projects and initiatives (Annex 2) will be used for the further development of synergies and collaborations. Moreover, the best practices gathered will be used to support the development of the HarvRESt Agricultural Virtual Power Plant (AVPP) which will be capable of running diverse scenarios and farm configurations and would determine the best operational procedures for a given RES solution. Based on data from the best practices gathered and AVPP another next step will be the development of a Decision Support System (DSS) to make recommendations of the best RES integration solutions & operation procedures for optimised production.

The findings from Task 2.2 offer valuable insights into the socio-economic, political and regulatory factors shaping the adoption of RES by farmers and rural communities across the UC regions. The application of the Technology Acceptance Model (TAM) has proven effective in understanding farmers' attitudes towards RES adoption, highlighting that perceived ease of use (PEU), perceived usefulness (PU), and environmental stewardship are primary drivers. While economic factors were not as influential as expected, the strong role of environmental concerns reinforces the need for sustainability-focused awareness-raising strategies. The study also identified significant barriers, including financial constraints, complex regulatory frameworks, and risk aversion, which must be addressed to facilitate broader adoption.

Building on these insights, the next steps will focus on developing strategies and co-creation activities tailored to the regional context and challenges, as well as the key stakeholder groups' profiles and needs. Financial incentives and technical support will be prioritised, together with efforts to simplify regulatory processes and reduce perceived risks. Integrating these strategies with the best practices from Task 2.1 will ensure a cohesive approach, grounded in both theoretical frameworks and practical application. Additionally, showcasing local success stories will be essential in promoting the social acceptability of RES, enhancing engagement, and ultimately driving adoption in agricultural settings.

Concerning to the Task 2.3, the main perceptions and objectives for each use case has been identified, and the agro-community characterisation has been done following the information provided by the UC partners. In this Deliverable 2.1, a summary of the agro-community characterization is included based on different factors such as location, climatological characteristics, natural resources, agricultural activities, energy demand and seasonality, the level of connection or accessibility to the grid, and data monitoring and digitalization systems. In addition, a section on "expected outcomes" has been added to each UC, which also includes a tentative list of the related KERs and KPIs.

In the next steps, all this information will be used to define the necessary KPIs in each UC and their interactions (Task 2.4). The agro-community characterisation will also be useful for the development of models within the framework of WP5. In addition, although the Task 2.3 is over, the co-creation approach continues with the establishment of the working groups composed by local stakeholders that will support the project execution in each UC (Task 2.5).

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8. ANNEXES

8.1 Annex 1: Summary Table for RES integration practices

RES technology	RES technology description	Farming type the RES can be applied to	Energy potential and conversion rate	Pros	Cons	Integration level
Solar – Photovoltaic panels on buildings	Solar photovoltaic panels installed on farm buildings convert sunlight into electricity through the photovoltaic effect.	Any farming type that there are buildings to be installed in proximity.	Multicrystalline silicon cells: 14%-19% [174] Monocrystalline silicon cells: even above 21% [174] Still angle, weather condition and installation properties playing a role [175]	-Reduces electricity costs by generating power on-site. -Low maintenance with minimal ongoing costs. [176]	-Initial farm infrastructure and shading [10] -Requires significant roof space for optimal efficiency. -Energy production varies with weather and daylight conditions.	High
Solar – Agrivoltaics	Solar agrivoltaics involves the dual use of land for both agriculture and solar energy production, where photovoltaic panels are installed above crops, allowing for electricity generation using the same principle as above, while still enabling crop growth. Agrivoltaics can be also coupled with animal husbandry as it can be used in combination with grazing.	Crops that are suitable: leafy greens, fodder varieties such as clover grass, several fruits and berries, herbs, and spices and vineyards. Like other crops, Lettuce adapts to shade by growing its leaf area in order to minimise the negative effects of the shade. Crops that are not suitable: potatoes, bell pepper, broccoli, salads, winter wheat etc. [10]	Same as above	-Positive impacts on biodiversity [3,14,17] -Positive impact in soil moisture [32] -Synergy on producing energy, food with less water	-Initial farm infrastructure, installation costs and shading [32] -Lack of specific definition, different requirements among member states and subsidies issues [15] -Competition and land prices rise [15] -Public awareness and acceptance the local community [15] -Maintenance challenges with both solar panels and crops. [15]	High
Solar – Solar PV fencing with vertical panels	Solar PV fencing with vertical panels involves the integration of photovoltaic panels into farm fencing, converting sunlight into electricity using the photovoltaic effect.	Not suitable for: High-density vegetable farms and intensive livestock as they could limit space and animal activity can produce damages	Same as above	-Utilizes fence space for energy generation. -Reduces visual impact compared to traditional panel arrays.	-Initial farm infrastructure influencing shading [10] -Limited energy output per unit area compared to larger solar installations.	Medium

		Suitable for: fruit orchards and vineyards (some grape varieties) as they can provide additional shading				
Solar – thermal energy production	Solar thermal energy production uses solar collectors to capture and convert sunlight into heat, which can be used for various farm applications such as water heating, space heating, or drying crops	Ideal for farm types that require hot water like greenhouses or they need energy to heat buildings (poultry, pigs)	Same as above	-Durable and long-lasting technology. [177] -Potential for integration with existing heating systems, allowing for hybrid solutions.	-High initial installation costs for solar thermal collectors and associated systems. - Limited to heat production and reducing its versatility compared to photovoltaic systems. - Performance varies with weather and seasonal changes.	High
Solar Pumping	Solar pumping systems use photovoltaic panels to convert sunlight into electricity, which powers pumps for irrigation, livestock watering, and other water management needs on the farm	Ideal for areas with unreliable or limited connection to the grid and small scale farmers [178]	Same as above	-Ideal for remote locations where extending the electricity grid is impractical or expensive. - Low maintenance requirements and reliable performance with minimal moving parts. [179]	-Limited capacity compared to grid-powered pumps, which may not be sufficient for large-scale irrigation needs. [179]	Medium
Solar powered machinery	Solar-powered machinery uses photovoltaic panels to generate electricity that directly powers farm equipment, such as tractors.	Any as it is not affecting farm type only the machinery used.	Same as above.	-Reduces fuel costs by utilizing solar energy to power machinery. - Ideal for remote or off-grid locations, where access to electricity or fuel might be limited. - Lower operating costs due to fewer mechanical components and reduced maintenance compared to traditional fuel-powered machinery. [32]	-High initial cost for solar panels and integration with machinery. - Limited power output compared to conventional fuel sources, which may not be sufficient for high-demand or heavy-duty equipment. -Dependent on sunlight conditions, which can affect performance and efficiency during cloudy or nighttime conditions. [32]	Medium
Wind – Large-scale wind turbines	Large-scale wind turbines harness wind energy to generate electricity on a substantial scale, with	Suitable for • Soybean • Corn	20-40% EPA and also need to know the capacity factor of 30-50% on when they are	-High energy output capable of generating substantial electricity, making it suitable for large	-High initial installation and maintenance costs for turbines and infrastructure. [10,29]	Low

	turbines positioned strategically to capture high wind speeds and produce renewable energy for farm operations.	• Grazing livestock [180]	used in maximum capacity [181]	farms or communities. [10] - Scalable with the potential to integrate multiple turbines for increased energy production.	-Visual and noise impact, which can be a concern for nearby residents and may affect farm aesthetics. [1] -Intermittent energy generation dependent on wind availability, requiring backup energy solutions or storage. [10,34] -Negative effects on bats and birds [182]	
Wind – Small wind systems	Small wind systems use compact wind turbines to generate electricity from lower wind speeds, providing a renewable energy source for individual farm operations or specific applications like irrigation.	Most farms and ranches have enough free land (an acre or more) to be able to use a small wind turbine. [183]	This produce higher electricity efficiency and the Betz theoretical limit is 59.3% [184]	-Lower installation costs compared to large-scale turbines, making it more accessible for small farms. -Suitable for localized energy needs, providing renewable power directly where it's needed. -Minimal visual and noise impact relative to larger turbines, blending more easily into rural landscapes.	-Performance depends on local wind conditions [10] -Potential maintenance issues with smaller turbines, which may have shorter lifespans and more frequent repairs.	High
Wind – Hybrid wind-solar systems	Hybrid wind-solar systems combine wind turbines and solar panels to generate electricity from both wind and sunlight.	Large scale farms and livestock business with enough hectares and space to accommodate wind turbines and PVs.	Depends on the configuration and the properties of the relevant system.	-Optimize energy production across varying weather conditions. -Complementary energy sources with wind and solar providing power at different times, enhancing overall energy reliability. [41] -Reduces dependency on a single energy source.	-Complex installation and maintenance due to the integration of both wind and solar technologies. - Higher initial costs for combining and managing both systems. - Space requirements may be significant, potentially limiting suitability for smaller farms or properties.	High
Biomass-Biogas-biodigesters	Biogas biodigesters use organic waste materials, such as animal manure or crop residues, to produce	Farms that produce enough biomass to support the anaerobic digestion plant.	Each cubic meter of biogas contains approximately 6 kWh of energy, and when converted to electricity, it	-Reduces waste by converting organic farm residues and manure into	-High initial capital investment for biodigester systems and infrastructure. [10,44]	High

	biogas through anaerobic digestion.	[185]	yields about 2 kWh. [186] But the impact of the feedstock used on the overall efficiency of the biodigesters is very important.	valuable energy and fertilizer. -Produces renewable energy in the form of biogas, which can be used for electricity, heating, or as a vehicle fuel. -Improves soil health with digestate, a nutrient-rich byproduct that can be used as a natural fertilizer. Easy access to the grid system [10, 187]	• Requires consistent feedstock supply and management to maintain optimal operation. • Maintenance and operational complexity can be demanding, requiring regular monitoring and management. [10]	
Biomass – Biogas plant/ Anaerobic digestion of wastewater	Plant that can process organic farm waste and sewage sludge to recover nutrients and produce biogas through anaerobic digestion, which can be used for energy and fertilization.	Same as above only focused on wastewater and non solid biomass.	The biogas efficiency rate is the same. But the biogas yield from wastewater varies significantly and from 380 to 639 m³ per ton of dry solids (DS), depending on the specific characteristics of the sludge and the conditions under which it is digested [188]	-Provides high-quality digestate that can be used as a nutrient-rich fertilizer for soil enhancement. [187] -Enhances resource efficiency by recycling nutrients from waste materials back into agriculture, promoting a circular economy.	-High initial setup and operational costs for anaerobic digesters and related infrastructure. [44] - Requires careful management of feedstock and process conditions to optimize biogas production and prevent operational issues. [10] -Potential odour and space issues associated with storing and handling large volumes of organic waste. [10]	Medium
Biomass – Biogas plant (Biohydrogen from anaerobic digestion)	After biogas is produced using one of the methods above then it can be converted to biohydrogen. The biogas is subjected to a reforming process, such as steam methane reforming or water gas shift reaction, to produce biohydrogen.	Same as above and biogas	Under ambient conditions, a cubic metre of hydrogen provides some 3 kWh, equivalent to 0.003 kWh per litre. Pressurised hydrogen contains about 0.5 kWh/litre at 200 bar, 1.1 kWh/litre at 500 bar and 1.4 kWh/litre at 700 bar. Very important also the type of feedstock [189]	-Utilizes diverse feedstocks, allowing for the conversion of various organic materials into biohydrogen, increasing resource efficiency and reducing waste -Can be easily store in the farm facilities. [10,32]	-Complex and costly process involving multiple stages, which requires significant investment. [44] - Requires advanced technology and infrastructure for efficient hydrogen production and storage, which may not be readily available in all regions. - Energy-intensive conversion process with potential inefficiencies in transforming biomass into biohydrogen [190]	High
Biomass-Biomethane-Upgraded biogas	Upgrading technologies, such as water scrubbing and membrane separation,	Same as biogas and then the subsequent	Same important the type of the feedstock for the overall yield.	-High-quality renewable fuel: Upgraded biogas is purified to produce	-High upgrading costs: The process of purifying biogas to biomethane involves expensive technologies and	High

	utilize the distinct properties of gases in biogas to separate and purify methane, with these methods currently accounting for nearly 60% of global biomethane production [191]	equipment for the methanization process.	Biomethane has an LHV of around 36 MJ/m^3. Since it is identical to natural gas, it can be used without requiring modifications to end-user equipment or transmission and distribution infrastructure. It is also completely compatible. for use in natural gas vehicles. [191]	biomethane, which is a clean and efficient fuel suitable for electricity generation, heating, and transportation. -Versatile application: Biomethane can be injected into the natural gas grid or used as a vehicle fuel, enhancing energy flexibility. [191]	infrastructure, increasing the overall investment required. [10,44] -Complexity in operation: The upgrading process involves advanced technology and requires careful management to ensure efficiency and quality of the biomethane produced. [192] - Requires a consistent biogas supply: The effectiveness of the upgrading process depends on a steady and reliable supply of biogas, which may be challenging to maintain.	
Biomass- Biomethane- Thermal gasification of solid biomass and consequent methanation	Thermal gasification converts solid biomass into syngas (carbon monoxide, hydrogen, and methane) at high temperatures and pressures. The syngas is then cleaned and methanated using a catalyst to produce pure biomethane, with any remaining CO_2 or water removed afterward [191]	Farms that produce woody and solid biomass and can then have the equipment for the cleaning of the syngas.	Same as above	-High energy density: Thermal gasification followed by methanation converts solid biomass into high-energy biomethane, which can be efficiently used for power generation and heating. - Reduces waste: Utilizes solid biomass, including agricultural residues and wood chips, converting them into valuable energy products and reducing landfill use. - Flexibility in feedstocks: Can process various types of solid biomass, providing a versatile solution for different agricultural and forestry residues. [191]	-Complex and costly process: The multi-stage process of gasification and methanation involves high capital investment and sophisticated technology. - Requires significant infrastructure: Needs substantial infrastructure for biomass handling, gasification equipment, and methanation facilities. [10]	Medium
Biomass – Biopower generation	Biopower generation involves the direct combustion of biomass to produce steam, which drives a turbine connected to an electrical generator, converting the thermal	Farms that can have access to biomass and agri-wastes.	1. Direct combustion of biomass for power generation has an efficiency of about 39–	-Utilizes waste products: Converts agricultural and forestry residues into energy. - Stable and reliable: Provides a consistent energy source with	-High initial capital cost: Requires significant investment in infrastructure. -Fuel supply challenges: Dependence on a steady and reliable supply of biomass, which can be variable or subject to price fluctuations.	Medium

	energy from burning biomass into electricity.		44%. This means that for every ton of biomass combusted, around 4.4 kWh of electricity is generated. [193]	relatively predictable performance, especially in areas with a steady supply of biomass.	-Potential environmental impact: Biomass combustion can produce emissions and ash, which need to be managed to minimize environmental effects.	
Biomass – Bioheat generation (CHP)	Bioheat generation through combined heat and power (CHP) systems involves the direct combustion of biomass to produce heat, which is then used for space heating, hot water, or industrial processes, while simultaneously generating electricity through a steam turbine or other technologies	Farms that can have access to biomass and agri-waste.	Overall Efficiency: Biomass CHP systems can achieve overall efficiencies of 80-90% when both heat and electricity are considered. This is significantly higher than traditional power plants that typically operate at 20-45% efficiency for electricity alone [194,195].	-Dual benefit: Combined Heat and Power (CHP) systems generate both electricity and heat from biomass. - Reduces energy costs: By generating both electricity and heat from a single biomass source, it lowers overall energy expenditures compared to separate systems. -Utilizes biomass waste: Converts agricultural and forestry residues into useful energy.	-High initial setup cost: Requires significant investment in CHP systems and biomass handling infrastructure. [10] - Operational complexity: Managing a CHP system can be complex, requiring skilled personnel for operation and maintenance [196] - Fuel supply dependence: Consistent biomass fuel supply is needed to maintain reliable operation, which can be challenging in areas with variable biomass availability.	High
Biomass – Biofuel production (bioethanol or biodiesel)	Bioethanol is produced through the fermentation of sugars from feedstocks such as beetroot or corn, where yeast converts the sugars into ethanol and carbon dioxide. This ethanol can then be used as a renewable fuel for transportation	Farms that can have access to biomass wastes and oils for biodiesel. As also the conversion equipment.	Bioethanol Conversion Energy Content: 1 litter of bioethanol has an energy content of approximately 21.4 MJ (megajoules) per litter. Equivalent to Gasoline: It takes about 1.7 litters of bioethanol to equal the energy content of 1 litter of gasoline. Biodiesel Conversion Energy Content: 1 litter of biodiesel has an energy content of around 32.7 MJ per liter.	-Utilizes agricultural byproducts: Produces biofuels from feedstocks like corn, sugarcane, or vegetable oils, which can help manage surplus agricultural products and waste.	-High production costs: Biofuel production can be expensive, involving significant costs for feedstock, processing, and infrastructure. - Land use competition: Growing biofuel feedstocks can compete with food crops for land, potentially impacting food prices and availability. [199] -Energy and resource intensity: The production process may require substantial energy and water, which can offset some environmental	Medium

			Equivalent to Diesel: Approximately 1.3 liters of biodiesel are needed to match the energy content of 1 liter of diesel [197] Type of feedstock plays also significant role. For bioethanol difference to first and second generation feedstock [198] and for biodiesel different between animal fat and waste greases, edible and non-edible oils [198]		benefits depending on the efficiency and scale of production. [200]	
Biomass – Biomass Pyrolysis and Biochar production	Biomass pyrolysis involves heating organic materials in the absence of oxygen to decompose them into biochar, bio-oil, and syngas. The biochar produced is a stable form of carbon that can be used as a soil amendment to improve soil fertility and sequester carbon	Farms with access to steady supply of biomass feedstock.	Mass and Energy Efficiency: The conversion of biomass to bio-oil has been reported to achieve a mass efficiency of approximately 19.65% and an energy efficiency of 29.10% when using electrical heating for pyrolysis. This energy efficiency can increase to 32.81% if a direct thermal source is used instead of electrical heating. [201] Yield of Products: In a study of sawdust biomass pyrolysis, the yields were reported as 26.5% for syngas, 34.9% for bio-oil, and 38.6% for biochar by weight	-Produces biochar, a stable form of carbon that improves soil health, increases soil fertility, and enhances water retention. - Reduces waste by converting biomass residues into valuable products, helping manage agricultural and forestry byproducts.	-High initial setup costs for pyrolysis equipment and infrastructure, which can be a barrier to implementation. [10] -Energy-intensive process: Pyrolysis requires significant energy input, which can impact the overall efficiency and cost-effectiveness of the technology.	High
Hydropower – Utilization of existing high pressurised irrigation systems	Utilization of existing irrigation systems for hydropower involves installing micro-hydropower turbines within existing irrigation	Farms with existing high-pressurised irrigation systems [202]	Integration with Irrigation Systems: Existing irrigation infrastructure, such as pressurized irrigation systems and irrigation ditches, can be adapted to generate	-Cost-effective integration: Utilizes existing infrastructure, reducing the need for new construction and lowering overall costs.	-Limited energy generation capacity: May not produce a large amount of electricity compared to dedicated hydropower plants, especially if the irrigation system has low flow rates.	Low

	infrastructure to generate electricity from the flow of water used for irrigation.		hydropower. This can be achieved through the installation of turbines that convert the kinetic energy of flowing water into electricity. Such systems can produce up to 2 megawatts (MW) of energy, making them suitable for small-scale agricultural operations [33]	- Low environmental impact: Typically involves minimal changes to the existing irrigation system, reducing potential ecological disruption.	- Complex integration: Adapting irrigation systems for energy production may require significant modifications and engineering expertise. - Potential impact on irrigation: Changes to the water flow for power generation could affect irrigation efficiency or water availability for crops- Energy use intensive as more water means more power generated.	
Hydropower – Pump as Turbines (PAT)	Pump as Turbines (PAT) technology repurposes existing water pumps to function as turbines, generating electricity from the flow of water in reverse, which can be harnessed in low-head or variable flow conditions for small-scale hydropower applications.	Same as above	Pump as Turbines (PATs): When using pumps as turbines, the efficiency can be lower, typically around 35% to 50%. This makes PATs less efficient than dedicated turbines but still a viable option for small-scale applications where cost and existing infrastructure are significant considerations [203]	-Cost-effective solution: Utilizes existing infrastructure such as water pumps, reducing the need for new equipment and lowering installation costs. -Flexible operation: Can function as both a pump and a turbine, allowing for energy generation during low-demand periods and water pumping during high-demand periods. -Efficient in low-head applications: Ideal for small-scale or low-head sites where traditional turbines may not be practical.	-Limited power output:100 kWh max Typically suitable for smaller-scale projects, which may not meet the energy needs of larger operations. -Performance dependency: Efficiency can vary with changes in water flow and pressure, potentially affecting overall energy generation. -Maintenance challenges: Requires careful management and maintenance of both the pumping and turbine functions to ensure reliable performance. [23]	Low
Hydropower – Smart Hydropower with in-stream turbines	Smart hydropower with in-stream turbines utilizes submerged turbines placed directly in river or stream currents to generate electricity from flowing water	Farms with access to water bodies with natural flow of water	Instream turbines can have efficiencies around 40% for recent designs [204]	-Minimal infrastructure impact: In-stream turbines are installed directly in rivers or streams without the need for large dams or significant alterations to water flow, reducing environmental disruption.	-Variable energy output: Power generation can be inconsistent due to fluctuations in water flow and stream conditions. -Potential ecological impact: Although less invasive than traditional dams, in-stream turbines can still affect local aquatic habitats and wildlife.	Low

				-Real-time optimization: Smart hydropower systems use advanced monitoring and control technologies to optimize energy production based on current water conditions and demand.	-Higher technology costs: Advanced monitoring and control systems can increase the overall cost and complexity of the installation and operation.	
Hydropower – Micro-hydropower (MHP)	Micro-hydropower (MHP) systems harness the energy of small, low-flow water sources to generate electricity on a small scale, often using compact turbines and generators suitable for remote or off-grid locations	Same as above	General Efficiency: MHP systems generally achieve efficiencies between 60% and 90%. The specific efficiency can depend on the design of the turbine and the characteristics of the water source. [205]	-Cost-effective for small-scale applications: Micro-hydropower systems are relatively inexpensive to install and operate, making them ideal for small farms or remote locations. -Low environmental impact: Typically has minimal effect on local ecosystems compared to larger hydropower projects, often using small streams or rivers without major alterations.	-Limited power generation: Generally, produces a small amount of electricity, which may not meet the energy needs of larger operations or high-demand applications. -Site-specific: Effectiveness depends on having suitable water flow and head height, which may not be available in all locations. [23] -Maintenance requirements: Regular upkeep and monitoring are needed to ensure reliable performance and address potential issues like debris or changes in water flow. [23]	Medium
Geothermal – Geothermal power plant	Geothermal power plants extract hot water or a mixture of water and steam from underground reservoirs to the surface, using the heat to generate steam that drives turbines and produces electricity [32]. Afterward, the cooled fluids are reinjected back into the reservoir to be reheated and reused [32]. The utilization of geothermal resources is for heating purposes.	Greenhouse farming, Feedstock with barns.	The conversion efficiency of geothermal power plants typically ranges from 10% to 20%, with the higher end representing plants that use pure vapor from the geothermal reservoir. The average worldwide conversion efficiency is around 12%. [206]	-Provides consistent and reliable energy: Geothermal power plants generate a steady and continuous supply of electricity, regardless of weather or time of day.	-High initial costs: Requires significant investment for drilling, plant construction, and infrastructure [54] - Geographic limitations: Effective only in regions with adequate geothermal resources, such as tectonic plate boundaries or volcanic areas. - Potential environmental concerns: May cause land subsidence or affect local geothermal reservoirs, requiring careful management and monitoring.	High

8.2 Annex 2: Related European projects and initiatives

Project acronym	Project/initiative full name	RES type	Country	Agri production type	Status
AgEnRes	AnalysinG of fossil-ENergy dependence in agriculture to increase RESilience against input price fluctuations	Multiple	EU	Multiple	Active (2024)
AgroFossilFree	The path towards a fossil-free EU agriculture	Solar/Wind/Biomass	EU	Multiple	Active (2020)
AGRORES Interreg	Investing in Renewable Energies for Agriculture	Solar/Wind/Biomass/Geothermal	EU and UK	Multiple	Closed (2019-2023)
BRANCHES	Boosting rural bioeconomy networks	Biomass	Germany, Finland, Italy, Spain and Poland	Multiple (incl. Forest)	Closed (2021-2023)
ClieNFarms	Climate Neutral Farms	Solar/Wind/Biomass	UK, Portugal, Spain, France, Belgium ,Netherlands, Germany, Switzerland, Poland, Italy, Ukraine, Romania and New Zeeland	Arable crops, Dairy, Monogastric, Beef, Sheep, Specialised crops	Active (2022)
Climate Farm Demo	Demonstration network on climate-smart farming	Solar/Wind/Biomass/Hydropower/Geothermal	EU and UK	Multiple	Active (2022)
ECOLOOP	Optimising renewable energy in rural areas for a sustainable and circular economy	Solar/Biomass/Geothermal	Bulgaria, Spain, Slovenia, Estonia	Multiple	Active (2023)
EU CAP Network	Formerly EIP Agri- Best practices hub				
HyPErFarm	Hydrogen and Photovoltaic Electrification on Farm	Solar (Hydrogen)/biomass	Belgium, Denmark, Germany,	Multiple	Active (2020)
PYRAGRAF	Decentralized pyrolytic conversion of agriculture and forestry wastes towards local circular value chains and sustainability	Solar/Biomass	Portugal, Germany, Turkey	Multiple	Active (2022)
RECAH	Rural Energy Community Advisory Hub				
RES4LIVE	Energy Smart Livestock Farming towards Zero Fossil Fuel Consumption	Solar/Biomass	Belgium, Greece, Italy and Germany	Livestock	Active (2020)
Smart Rural 27 Project	Knowledge Cluster on renewable energy communities				

Tractofit'Elec	agriculTurE wAste PyrOlysis and Thermocomposting for renewable energy in Sustainable agri-food sector	Biomass	Italy, Greece, Germany, Czechia, Netherlands, Portugal	Multiple	Active (2022)
Value4Farms	Converting agricultural tractors to electricity	Not mentioned specifically	Multiple	Multiple	Active
Vitisolar	Sustainable renewable energy VALUE chains for answering FARMers' needs	Solar/Biomass	Iceland, UK, France, Belgium, Germany, Italy, Denmark, Poland, Croatia	Multiple	Active (2023)
BIOREGIO Interreg	Vineyard Agrivoltaism Pilot	Solar	France	Vineyard	Active (2023)
VidVolt 4.0	Regional circular economy models and best available technologies for biological streams	Biomass	Multiple	Multiple	Closed (2018-2022)
LIFE REWIND	Implementation of Artificial Intelligence in agrovoltaic vineyard sites	Solar	Spain	Vineyard	Active (2023)
FUELPHORIA	Renewable energy in the wine industry	Solar (hydrogen)	Spain	Vineyard and Winery	Closed (2014-2017)
FERTIMANURE	Accelerating the sustainable production of advanced biofuels and RFNBOs – from feedstock to end-use	Biomass	Spain, Greece, Belgium	Winery, feedstock	Active (2023)
LIFE+_Climate changE-R	innovative nutrient recovery from secondary sources for the production of high-added value FERTIlisers from animal MANURE	Biomass	EU	Multiple	Closed (2020-2024)
LIFE LIVE-WASTE	Reduction of greenhouse gases from agricultural systems of Emilia-Romagna	-	Italy	Tomato, green bean,	-
O'MEGA 1	Sustainable management of livestock waste for the removal/recovery of nutrients	Biomass	Cyprus, Greece, Spain, Italy	Livestock Waste	Closed (2013-2016)
ESEK	Boosting the European market for biogas production,	Biogas	EU	Multiple	Closed (2012-2014)
DoppelErnte/SCHLETTER	upgrade and feed-in into the natural gas grid				
Eyragues Greenhouse (AMARENCO)	Floating PV's with 6 hectares of municipal land experimentation on using the energy produced by the floating PVs for the needs of various crops.	Solar	France	Multiple (incl. Forest)	Active
ENEL Green Power Demonstration	bioenergy from crop residues by an energy community in Thesally	Biomass	Greece	Crop Waste	Active

AKUO Bellegarde	AGRI-PV TRACKER SYSTEM IN BAVARIA	Solar	Germany	Multiple	Active
Agriteos	STRAWBERRY PV GREENHOUSES IN EYRARGUES, BOUCHES DU RHONE, FRANCE	Solar	France	Strawberries and market garden crops	Active
RESFARM	INTRODUCING AGRICULTURE IN EXISTING SOLAR PLANTS ACROSS EUROPE	Solar	Spain, Italy, Greece	Variety of crops	Active
PanePowerSW	BELLEGARD ORCHARD IN OCCITANIA AND AGRI-PV INSTALATION	Solar	France	Apricots, Beekeeping	Active
OZERISE	Agri-PV project on Plum Trees farm	Solar	France	Multiple	Active
LIFE VINEYARDS4HEAT (V4H)	Developing and implementing financial instruments for the mobilisation of investments in renewable energy in the agrarian sector	Multiple	Spain, Italy, Greece	Multiple	Active
LIFE SMART AgroMobility	Transparent Solar Panel Technology for Energy Autonomous Greenhouses	Agri-PV	Greece	Vineyard	Active
LIFE22-CCM-DE-LIFE EU LEAD PV	Agricultural farms and smart grids integrated renewable energy sources	Solar/Wind/ Biomass	Poland	Multiple	Closed (September 2012-June 2015)
FIMUSKRAFT	Vineyards for carbon footprint reduction: a sustainable strategy to use biomass for heat & cold in wineries.	Biomass	Spain	Vineyards/Winery	Closed (2014-2017)
BioFuel Fab	Processing of livestock waste, for the production of biomethane for use in agricultural vehicles and biofertilizers	Biomass	Spain, Belgium	Multiple	Closed (2020-June 2024)
ALFA	Land use efficient, agriculturally sound large scale photovoltaics	Solar	Spain, France and Germany	Arable Crops	Active
GEOTHERMIKI HELLAS	Biotechnological production of energy by electrification of biowaste	Biomass	Finland	Multiple	Active
High Energy Project	Biogas production from non-food lignocellulosic biomass waste.	Biomass	Finland	Multiple	Active
WENDY	Upscaling the market uptake of renewable energy by unlocking the biogas potential of livestock farming https://www.europeanbiogas.eu/turning-farm-waste-into-renewable-energy-the-alfa-story/	Biomass	Belgium, Denmark, Germany, Greece, Italy, Slovakia, Spain	Livestock	Active
CYBELE	cultivation of various food products with the use of geothermal energy and a drying plant using geothermal energy	Geothermal	Greece	Market vegetables and dried food products	Active

ELEXIA	use of existing wind tourbines to power greenhouses in the southern Ontario, Canada	Wind	Canada	Greenhouses	Active
BeCOOP	A project to build multi-spatial planning and integrating assesment tool to enhance social acceptance of wind farms	Wind	Belgium, Denmark, Greece, Italy, Norway, Spain	Multiple	Active
SEMPRE-BIO	A project to use HPC, Big Data, Cloud Computing (services) and the IoT in agriculture to boost energy efficiency, agri-food value chains and sustainability	Precision Agriculture and digitalisation	EU and UK	Multiple	Active
SYNERGY	A project to integrate energy systems and facilitate the shift towards digital transition	Energy Management System		Multiple	Active
HydroGlen Project	The ambition of BECoop (2020-2023) is to provide the necessary conditions, technical as well as business support tools, for unlocking the underlying market potential of community bioenergy, fostering new links and partnerships	Biomass	Poland, Spain, Greece, Germany,	Multiple	Active (2020)
Green VALLeys	At SEMPRE-BIO (SEcuring doMestic PRoduction of cost-Effective BIOmethane) we will establish three European Biomethane Innovation Ecosystems (EBIEs) in Baix Llobregat (ES), Bourges (FR), and Adinkerke (BE) where five biomethane innovations technologies will be tested.	Biomass	France, Spain and Belgium, Germany, Denmark, Norway	Multiple	Active (2023)
GOTEFCOR	SYNERGY introduces a novel framework in response to the need for “end-to-end” coordination between the electricity stakeholders – not only in business terms but also in exchanging information.	Energy Management System	Spain, Greece, Finland, Cyprus, Croatia, Italy, Portugal, Austria, Denmark		Active (2020)
Smartgas	HydroGlen Renewable Hydrogen Powered Farm	Hydrogen (GREEN from Wind/Solar)	Scotland	Multiple	Active
Agrocycle	Green biorefineries for sustainable production of bioenergy from agriculture	Biomass	Sweden, Denmark	Multiple	Active (2020)
CONVERGE	GOTECFOR - Technology for the mobilization and use of forest biomass in agro-industry	Biomass	Portugal	Multiple	Closed (2017-2020)
LIFE SEED CAPITAL	farming with biogas to reduce carbon footprint and increase sustainability and resilience to climate change of cropping systems for quality	Biomass	Italy	Vegetable Crops	Closed (2020-2023)
LIFE-CO2-INT-BIO	Sustainable techno-economic solutions for the agricultural value chain	Biomass	Spain, Ireland, Croatia, Greece, Germany, UK, Hong Kong, China, Italy, Belgium	Multiple	Closed (2020-2023)

eGIS	CarbON Valorisation in Energy-efficient Green fuels	Biomass	Netherlands, Romania, Slovenia, Spain, Norway, Sweden, Italy, Slovakia	Multiple	Closed (2018-2022)
C-HEAT	INTEGRAL USE OF OIL SEEDS TO REDUCE GREEN HOUSE GASES EMISSIONS ASSOCIATED WITH FARMING ACTIVITIES	Biomass	Spain	Oil Seeds	Closed (2013-2016)
ECO-LOGIC GREEN FARM	CO_2 emissions reduction by industrial integration and value chains creation	Biomass	Spain	Greenhouses	Closed (2020-2023)
Residue2Heat	EGIS- ENERGY VILLAGE	Solar	Germany	Arable Crops	Active
VegWaMus CirCrop	Condensed Heat- Optimization and scaling up of an energy efficient, long-during biomass condensation boiler with curved heat exchanger	Biomass	Spain	Multiple	Closed (2016-2018)
Livestock exploitation in Galicia	Design of an agricultural greenhouse for intensive growing of microalgae in fresh / sea water with a syngas production plant and organic farming of chickens and pigs outdoors.	Biomass	Italy	Multiple	Closed (2015-2017)
BIOMAN	Renewable residential heating with fast pyrolysis bio-oil	Biomass	Germany	Multiple	Closed (2016-2019)
DualMetha	Developing commercial mushroom and vegetable production in an integrated food to waste to food biosystem	Biomass	Norway, Finland, Poland	Greenhouses (mushrooms and vegetables)	Closed (2015-2017)
APV Obstbau	Livestock exploitation in Galicia	Wind and Solar	Spain	Livestock, Dairy	Active
NoAW	Economically efficient biogas production from manure fibres and straw	Biomass	Denmark, Spain, Germany, UK	Multiple	Closed (2012-2015)
Solar pumping for irrigation with solar trackers	A cost-effective process for methanisation of unexploited agricultural waste.	Biomass	France	Multiple	Closed (2018)
Energy efficient straw boiler with low NOx emission	Agrophotovoltaics as a resilience concept for adapting to climate change in fruit growing	Solar	Germany	Apples	Active
WASTE2WATTS	Innovative approaches to turn agricultural waste into ecological and economic assets	Biomass	Denmark, Sweden, Portugal, Netherlands, France, Germany, Hungary, Serbia, Greece, Italy	Multiple	Closed (2016-2021)
AGROinLOG	Solar pumping for irrigation with solar trackers	Solar	Spain	Multiple	Active
BISON	Energy efficient straw boiler with low NOx emission	Biomass	Denmark	Multiple	Active

HIPERION	Unlocking unused bio-WASTE resources with loW cost cleAning and Thermal inTegration with Solid oxide fuel cells	Biomass	Switzerland, France, Italy, Germany	Multiple	Closed (2019-2023)
ICaRE4Farms	Demonstration of innovative integrated biomass logistics centres for the Agro-industry sector in Europe	Biomass	Spain, Belgium, Netherlands, Italy, Sweden, Serbia, Ukraine, Greece	Multiple	Closed (2016-2020)
BioVill	BIOMASS INTEGRATION FOR SYSTEM OPTIMISATION IN THE HÜMMLING ENERGY REGION	Biomass	Germany	Multiple	Closed (2019-2021)
GW-FortyForty (2016)	HYBRID PHOTOVOLTAICS FOR EFFICIENCY RECORD USING INTEGRATED OPTICAL TECHNOLOGY	Solar	Switzerland, Germany, Spain, Ireland, Czechia, UK, Poland, Belgium, Portugal, France	Multiple	Closed (2019-2023)
AgrowFab	Increase the capacity of Renewable Energies (RE) in Farms in the North West Europe Region by using Solar Thermal Energy	Solar	UK, Belgium, Netherlands, France	Greenhouses, Livestock	Closed (2019-2022)
SULTAN	Bioenergy Villages (BioVill)- Increasing the Market Uptake of Sustainable Bioenergy	Biomass	Germany, Austria, Croatia, Romania, Slovenia, Serbia	Multiple	Closed (2016-2019)
Eciwind	Gaia-Wind's Advanced Small Wind Turbine FortyForty	Wind	UK	Multiple	Closed (2016)
BABET-REAL5	Far Infrared Radiation Smart Fabric Heating Element for GreenHouses	Heating fabric comprising nylon fibers	Israel	Greenhouses	Closed (2016)
PVCROPS	SUstainabLe Tunnel Agriculture with light cascade techNology	Microclimatic Tunels	France	Greenhouses	Closed (2015)
HyPump	Cost effective wind turbine of 40 kW of rated capacity	Wind	Spain	Multiple	Closed (2015-2018)
SEFI	New technology and strategy for a large and sustainable deployment of second generation biofuel in rural areas	Biomass	Mexico, Spain, France, Portugal, Germany, Denmark, Argentina, Uruguay	Multiple	Closed (2016-2020)
Solar-Win	PhotoVoltaic Cost r€duction, Reliability, Operational performance, Prediction and Simulation	Solar	Spain, Portugal, Bulgaria, Morocco, Ireland, France, Belgium	Multiple	Closed (2012-2015)

INNOWIND	Enabling Sustainable Irrigation through Hydro-Powered Pumps for Canals	Hydro	Netherlands	Access to canals and water bodies	Closed (2017-2020)
SolAqua	Solar Energy for Food Industry	Solar	Austria, Netherlands, Spain	Multiple	Closed (2015)
SUNINBOX	Next generation transparent solar windows based on customised integrated photovoltaics	Solar	Austria, Netherlands, Spain	Farms with buildings with windows	Closed (2019-2021)

8.3 Annex 3: Online form to collect input on interviewees

HarvRESt T2.2 Interviews

In the context of Task 2.2, local pilot partners will need to conduct **5 interviews per pilot area**, to investigate the current framework conditions at use case level and examine how, why and under what conditions these act as a barrier or an enabler for the uptake of RES at farm level.

White Research will provide the guidelines and list of questions to facilitate the process, while all partners involved will be asked to share their input. These interviews are expected to be completed by early May.

Here, the use cases' teams (Italy - TECNO, CONFAGRI, FSDC, EnG, Denmark - CT, FBCD, Spain - VdV, VRT, ACSA, BETA & CIRCE, Norway - GGE, NORCE) are kindly asked to provide their suggestions for the interviewees.

Please, kindly make sure to cover at least 2 farmers/rural actors, 1 public authority, 1 energy community member, and 1 representative of the energy industry.

Please indicate below your input on potential candidates.

* Indicates required question

1. Email *

2. Please select your Use case - Country *

   Mark only one oval.

   - Spain
   - Italy
   - Denmark
   - Norway

3. Partner name *

Candidates for Interviews

4. Please indicate the candidate's name

5. Please indicate the candidate's position/organisation *

6. Why do you recommend this candidate for an interview? *

7. Please indicate here the contact details of the candidate (e-mail address)

Candidates for Interviews

8. Please indicate the candidate's name

9. Please indicate the candidate's position/organisation *

10. Why do you recommend this candidate for an interview? *

11. Please indicate here the contact details of the candidate (e-mail address)

Candidates for Interviews

12. Please indicate the candidate's name

13. Please indicate the candidate's position/organisation *

14. Why do you recommend this candidate for an interview? *

15. Please indicate here the contact details of the candidate (e-mail address)

Candidates for Interviews

16. Please indicate the candidate's name

17. Please indicate the candidate's position/organisation *

18. Why do you recommend this candidate for an interview? *

19. Please indicate here the contact details of the candidate (e-mail address)

Candidates for Interviews

20. Please indicate the candidate's name

21. Please indicate the candidate's position/organisation *

22. Why do you recommend this candidate for an interview? *

23. Please indicate here the contact details of the candidate (e-mail address)

Candidates for Interviews

24. Please suggest any additional candidates

8.4 Annex 4: Interview guides

8.4.1 *Topics covered by each interview questionnaire*

Q1 - Farmers	Q2 - Energy Communities / Cooperatives/ Organisations	Q3 – Energy Industry actors	Q4 - Public Authorities
• Farming Experience and Context • Perception of Greenhouse Gas Emissions • Familiarity with RES • Adoption of RES • Perceived Benefits of Adopting RES • Motivating Factors for Implementing RES • Barriers to Adoption of RES • Importance of Economic Factors • Willingness to Invest in Clean Energy • Environmental Responsibility • Future Integration of RES • Role of HarvRESt	• History and Activities of Energy Community /Cooperative • Familiarity with Existing RES Initiatives in Farming • Primary Motivations and Incentives for Adopting RES in Farming • Significant Barriers or Challenges for RES Adoption in Farming • Strategies to Address Barriers and Capitalise on Opportunities • Governance or Business Model for Facilitating RES Uptake • Envisioned Cooperation with Key Actors • Relevance of RES Integration in Farming • Opportunities for Further RES Integration in Farming • Role of Energy Communities in Promoting Environmental Stewardship and Sustainable Development • Role of HarvRESt	• Overview of Company's Involvement in the Energy Sector • Current Regional Landscape for RES in Agriculture • Company Initiatives or Projects for RES Integration in Agriculture • Perceived Importance of Integrating RES into Farming Practices • Primary Motivations or Incentives for Promoting RES in Agriculture • Significant Barriers or Challenges for RES Adoption in Farming • Impact of Financial Considerations on RES Adoption at the Farm Level • Role in Promoting Environmental Stewardship and Sustainable Development through RES • Opportunities for Further Integration of RES into Farming Practices • Key Alliances or Partnerships for Implementing RES in Agriculture • Role of HarvRESt	• Role and Responsibilities of Public Authorities • Role of Institution in RES Integration • Existing Policies, Regulations, and Incentives • Challenges and Obstacles for Promoting RES Adoption • Collaboration with Stakeholders • Public Authorities' Role in Providing Support • Prioritisation of Competing Interests • Monitoring and Evaluation Mechanisms • Emerging Trends and Innovative Approaches • Future Opportunities and Challenges • Role of HarvRESt in Supporting RES Integration

8.4.2 *Interviews' questionnaires*

Q1. Semi-Structured Interview Guide – Farmers

Sex of respondent: female/male

Country:

Position/Organisation:

Questions

1. Can you briefly tell me about your farming experience, including how many years you have worked as a farmer/agricultural cooperative, what type of farming activities, and how are you funded? Support question: if the answer is brief, encourage the participant to elaborate on the agricultural/farming context in their region.

2. We want to hear your perspective on farming and greenhouse emissions. Do you believe that farming activities on farms contribute to greenhouse gas emissions? Why or why not?

3. Are you familiar with renewable energy sources in agriculture? Which technologies are you familiar with? Follow-up/support question: What is the situation in your region?

4. Have you adopted a RES on your farm? If yes, kindly invite the participant to share their experience (which technology, for how long, etc.). If no, jump to question 5.

5. Do you think adopting renewable energy sources on your farm would bring benefits to farmers? If yes, why, and which ones? If not, please further elaborate.

6. What factors do you think would motivate or encourage you to consider implementing/adopting renewable energy sources on your farm? (if they already have a RES, to expand)

7. What barriers or obstacles exist now in your region/area that might make the adoption of renewable energy sources on your farm difficult?

8. How important are factors such as personal expenses, evidence of economic benefits, and potential cost savings when making decisions about energy use or other innovations on your farm?

9. Would you be willing to invest additional funds to access clean energy through renewable sources?

10. Do you believe it is your responsibility to contribute to environmental protection through your farming practices? How do you balance environmental conservation efforts with economic considerations on your farm?

11. What are your thoughts on integrating RES into farming practices in the future?

12. Optional: how do they envision the role of a project like HarvRESt to support the integration of RES at the farm level?

Q2. Semi-Structured Interview Guide – Energy Communities / Cooperatives / Organisations

Sex of respondent: female/male

Country:

Position/Organisation:

Questions:

1. Can you briefly introduce the history and activities of {name of energy community/cooperative}, including your experience within the organisation?

The interviewer can suggest elements such as: which actors are involved, how it is funded, how it is governed, etc.

2. Are you familiar with existing initiatives or projects that integrate renewable energy sources into farming within your region? Is your cooperative/community involved? Could you provide some examples or insights? (including with type of RES, actors involved, etc.).
3. In your opinion, what are the primary motivations or incentives for energy communities/cooperatives to get involved or promote the adoption of renewable energy sources in farming? Are there opportunities or synergies to explore?
4. What do you perceive as the most significant barriers or challenges hindering the widespread adoption of renewable energy sources in farming practices in your area or region from the perspective of small-size energy communities/communities?
5. Factors that can be suggested if the interviewee doesn't seem familiar: technological limitations/challenges, administrative procedures, policy incentives, access to funding, etc.
6. What strategies could be adopted to address these barriers and capitalize on the opportunities and incentives?
7. Based on your experience, what governance model or business model could facilitate the uptake and social acceptance of RES in farming?
8. How do you envision cooperation between energy communities/cooperatives with other key actors, such as farmers and energy industry actors? What would this cooperation look like?
9. From your perspective, how relevant do you believe the integration of renewable energy sources into farming practices is?
10. What opportunities do you envision for further integration of RES into farming practices and what is the role that energy communities/cooperatives can play?
11. How do you view the role of energy communities in promoting environmental stewardship and sustainable development through the adoption of renewable energy sources in farming practices
12. Optional.: how do they envision the role of a project like HarvRESt to support the integration of RES at the farm level?

Q3. Semi-Structured Interview Guide – Energy Industry Actors

Sex of respondent: female/male

Country:

Position/Organisation:

Questions:

1. Can you provide an overview of your company's involvement in the energy sector, including your experience within the organisation?

2. How would you describe the current regional landscape for the Energy sector/industry in terms of RES in agriculture?

3. In which initiatives or projects regarding the integration of RES into practices has your company been involved in the last years? Please, provide examples and insights.

4. How does your company perceive the importance of integrating renewable energy sources into farming practices for sustainable energy solutions and agricultural development?

5. What do you see as the primary motivations or incentives for energy industry actors, such as your company, to promote the adoption of renewable energy sources in agriculture? Are there any potential synergies or opportunities to explore in this regard?

6. Based on your experience in this sector, what are the significant barriers or challenges hindering the widespread adoption of renewable energy sources in farming practices in your area or region? Factors that can be suggested if the interviewee doesn't seem familiar: technological limitations/challenges, administrative procedures, policy incentives, access to funding, societal acceptance, landscape conflicts, etc.

7. To what extent do financial considerations, such as upfront investment costs and long-term economic viability, impact the decision-making process of adopting renewable energy sources at the farm level?

8. How does the energy sector/industry envision its role in promoting environmental stewardship and sustainable development through the adoption of renewable energy sources in farming practices?

9. What opportunities do you foresee for further integration of renewable energy sources into farming practices from the energy sector point of view? How does your company plan to capitalize on these opportunities?

10. What key alliances or partnerships would the energy industry sector consider essential to implement/adopt RES in agriculture?

11. Follow-up question HarvRESt role

Q4. Semi-Structured Interview Guide – Public Authorities

Sex of respondent: female/male

Country:

Position/Organisation:

Questions:

1. Could you please provide an overview of your role and responsibilities in {name of institution}? How long have you been working here? In which projects or initiatives related to RES integration in farming have you been involved?

2. What's the role of [name of institution} concerning RES integration in farming in your region?

3. What are the most relevant/important \ policies, regulations, or incentives in place within your region to encourage the adoption of RES in farming? If so, could you elaborate on their effectiveness and impact?

4. What are the main challenges or obstacles faced by public authorities in promoting the adoption of renewable energy sources among farmers? What strategies are being used to address these issues?

5. How do you collaborate with other stakeholders, such as agricultural organisations, energy companies, and research institutions, to support and promote the integration of renewable energy sources into farming practices?

6. In your opinion, what role should public authorities play in providing technical assistance, funding support, or capacity-building programs to help farmers adopt renewable energy technologies? What are the priorities for the upcoming years?

7. How do you prioritize between competing interests, such as economic development, environmental conservation, and energy security, when formulating policies or strategies related to renewable energy integration in farming?

8. What mechanisms are in place to monitor and evaluate the effectiveness of renewable energy initiatives in farming, and how do you use this information to inform future decision-making and policy development?

9. Are there any emerging trends or innovative approaches in renewable energy and farming integration that public authorities are particularly interested in exploring or supporting?

10. In the short-mid term future, are the key opportunities and challenges public authorities anticipate in further promoting the adoption of renewable energy sources in farming practices, and what strategies are being considered to capitalize on these opportunities and address these challenges?

11. Optional: how do they envision the role of a project like HarvRESt to support the integration of RES at the farm level?

8.5 Annex 5: Survey

The research questions (RQs) that guided the HarvREStt survey were:

- **RQ1:** What are the primary drivers and barriers in establishing RES among farmers?
- **RQ2:** To what extent do perceptions of usefulness and ease of use influence farmers' intentions to adopt renewable energy technologies on their farms?
- **RQ3:** How important are the perceived economic benefits of adopting RES?
- **RQ4:** Does risk aversion affect farmers' willingness to innovate with RES? Does it relate to their technology acceptance model (TAM) scores?

8.5.1 *List of variables assessed through the survey*

Intention: Based on a previously validated set of questions by [70], we evaluated the farmers' intention to adopt a RES. The participants indicated the extent to which they would install a RES with a set of three questions on a 5-point scale (1 = strongly disagree and 5 = strongly agree).

Attitude: Based on the questions [70] presented in their work, we studied the farmers' attitudes towards RES uptake with a series of four questions on a 5-point scale (1 = strongly disagree and 5 = strongly agree).

Perceived ease of use (PEU) and Perceived usefulness (PU): Following the approach [71] introduced the farmers expressed their subjective PEU and PU by answering a series of questions on a 5-point scale (1 = strongly disagree and 5 = strongly agree).

Economic interest and Environmental stewardship were assessed based on the questions utilised by (Floress, 2017). Participants responded how important are specific economic aspects for them on a 5-point scale (1 = not important and 5 = very important). Furthermore, they expressed on a 5-point scale how much they agree or disagree with 4 items related to environmental stewardship (1 = strongly disagree and 5 = strongly agree).

Risk aversion: Farmers were asked a set of four questions previously used by (Sulewski, 2014) to evaluate the participants' level of risk aversion in various contexts, including general risk aversion and risk aversion in personal health and financial matters and farming methods. Farmers answered how would they describe themselves on a 5-point scale (1 = no risk aversion and 5 = very high-risk aversion).

Drivers for adopting a RES (Table 14): To identify the potential drivers for establishing a RES farmers were asked to choose those that apply between nine items (high social acceptance, energy availability, power reliability, economic profit, environment protection, innovation and development interest, new job opportunities, strong farmer–agricultural organisation relationship, and further education opportunities) based on the work of [207].

Barriers to adopting a RES (Table 14): Similarly, based on [82], we studied the barriers farmers might experience to adopting a RES. Participants could select those that might apply between the following nine items: uncertainty about future requirements, financial barriers (high interest rates, low farmer income, high maintenance/installation costs), the difficulty of all energy stakeholders to cooperate with each other, lack of sectoral qualified workforce, economic profit, bureaucratic barriers, fear of a negative impact on human health (noise), landscape disruption, negative impact on wildlife and birds.

Renewable energy installations: In accordance with [68], participants were asked to report what renewable energy installations in their local community they are aware of.

Communication channels: Inspired by the work of Pombo-Romero [137], farmers were asked to choose the communication channels they prefer to acquire information regarding any new technology that might interest them.

Demographics: Several demographic items were included in the survey questionnaire, such as gender, age, area of residence, educational level, household income, and information regarding the farms they own or work at.

Table 14. Drivers and barriers for establishing a RES

Drivers/Barriers No	Description
Driver D1	High social acceptance
Driver D2	Energy availability
Driver D3	Power reliability
Driver D4	Economic profit
Driver D5	Environment protection (clean energy)
Driver D6	Innovation and development interest
Driver D7	New job opportunities
Driver D8	Strong farmer – agricultural organisation relationship
Driver D9	Further education opportunities
Barrier B1	Uncertainty about future requirements
Barrier B2	Financial barriers (high interest rates, low farmer income, high maintenance/installation costs)
Barrier B3	Difficulty of all energy stakeholders to cooperate with each other
Barrier B4	Lack of sectoral qualified workforce
Barrier B5	Economic profit
Barrier B6	Bureaucratic barriers
Barrier B7	Fear of a negative impact on human health (noise)
Barrier B8	Landscape disruption
Barrier B9	Negative impact on wildlife and birds

8.5.2 *Survey questionnaire*

The survey started with informed consent, including the following information: the study purpose, the survey procedure, the privacy policy, and the participant's rights when contributing to this study.

Demographics

1. What gender do you identify as?
   a. Male
   b. Female
   c. Prefer not to say
   d. Other (please specify): ____________________
2. What is your age?

   ____

3. What is your city/town/village of residence?

   ____

4. What is the highest level of education you have completed?
   a. Did Not Complete High School
   b. High School/GED
   c. Some College
   d. Bachelor's Degree
   e. Master's Degree
   f. Advanced Graduate work or Ph.D.
5. What is your net annual household income (in euros)?
   a. 5.000 € or less
   b. 5.001 € - 15.000 €
   c. 15.001 € - 25.000 €
   d. 25.001 € - 35.000 €
   e. 35.001 € - 45.000 €
   f. 45.001 € - 55.000 €
   g. 55.001 € - 65.000 €
   h. 65.001 € - 75.000 €
   i. 75.001 or more
   j. Prefer not to say
6. How many years of farming experience do you have?
   a. Less than 1 year
   b. 1 – 3 years
   c. 3 - 6 years
   d. 6 – 9 years
   e. Above 9 years
   f. Prefer not to say
7. Farm size
   a. Under 5 ha
   b. 5 – 20 ha
   c. 20 – 50 ha
   d. 50 – 100 ha
   e. 100 ha and above
   f. Prefer not to say
8. Type of farm tenure
   a. Wholly tenanted
   b. Mainly tenanted
   c. Mainly owned
   d. Wholly owned
   e. Prefer not to say
9. What is the primary focus of your farming activities?
   a. Crop production
   b. Livestock
   c. Mixed (crop and livestock)
   d. Other (please specify): __________________
10. Do you believe your farm emits greenhouse gases?
   a. Yes
   b. No
11. What are the potential drivers for establishing a renewable energy source? (Choose all that apply)
   a. High social acceptance
   b. Energy availability
   c. Power reliability

d. Economic profit
e. Environment protection (clean energy)
f. Innovation and development interest
g. New job opportunities
h. Strong farmer–agricultural organisation relationship
i. Further education opportunities

12. **What are the potential barriers to establishing a renewable energy source? (Choose all that apply)**
a. Uncertainty about future requirements
b. Financial barriers (high interest rates, low farmer income, high maintenance/installation costs)
c. Difficulty of all energy stakeholders to cooperate with each other
d. Lack of sectoral qualified workforce
e. Economic profit
f. Bureaucratic barriers
g. Fear of a negative impact on human health (noise)
h. Landscape disruption
i. Negative impact on wildlife and birds

13. **Are there renewable energy installations in your commune?**

	Yes	No	I don't know
Hydroenergy			
Photovoltaics			
Wind energy			
Biogas plants			
Biomass energy			
Geothermal energy			

Communication channels

14. **Which communication channels do you use to obtain information regarding new technologies in general?**
a. cooperatives/associations
b. technology providers
c. independent experts
d. other farmers
e. exhibitions
f. products' buyers
g. agrarian external services
h. other institutions

Technology Acceptance Model (TAM): intention

Please indicate your agreement with the following statements
[1=Strongly disagree; 2=Disagree; 3=Neither agree nor disagree; 4=Agree; 5=Strongly agree]

	1	2	3	4	5
15. **I will try to use RES at my farm in the future.**					
16. **I will strongly recommend that others use RES and its related technologies.**					
17. **I intend to use RES at my farm in order to supply a part of my required energy.**					

Technology Acceptance Model (TAM): Attitude

Please indicate your agreement with the following statements
[1=Strongly disagree; 2=Disagree; 3=Neither agree nor disagree; 4=Agree; 5=Strongly agree]

	1	2	3	4	5
18. In my opinion, the use of RES at farms is beneficial and valuable.					
19. Given the high cost and polluting nature of fossil fuels (e.g., petroleum, natural gas, and coal), I believe that using RES is extremely wise.					
20. I agree to pay additional money in order to receive clean energy through RES.					
21. I discovered that the quality of RES-related products is not as good as that of ordinary products.					
22. I strongly agree with the use of RES at my home or farm.					

Perceived Ease of Use (PEU)

Please indicate your agreement with the following statements
[1=Strongly disagree; 2=Disagree; 3=Neither agree nor disagree; 4=Agree; 5=Strongly agree]

	1	2	3	4	5
23. It is easy for me to become skilful at using renewable energy technology.					
24. If I encounter a difficult issue when using renewable energy, it would be easy for me to seek help.					
25. Overall, I find renewable energy technology is easy to use.					

Perceived Usefulness (PU)

Please indicate your agreement with the following statements
[1=Strongly disagree; 2=Disagree; 3=Neither agree nor disagree; 4=Agree; 5=Strongly agree]

	1	2	3	4	5
26. Renewable energy technology improves the work quality at farms.					
27. Continuous use of renewable energy technology enables me to reduce my farm costs.					
28. Using renewable energy technology enhances the effectiveness of using energy.					

Economic interest

29. How important are the following when you are making decision about the energy use in your farm?

[1=Not important; 2=Slightly important; 3=Moderately important; 4=Important; 5=Very important]

	1	2	3	4	5
Personal out-of-pocket expense					
Evidence of the economic benefits					
Saving money					

Environmental Stewardship

Please indicate your agreement with the following statements
[1=Strongly disagree; 2=Disagree; 3=Neither agree nor disagree; 4=Agree; 5=Strongly agree]

	1	2	3	4	5
29. It is my personal responsibility to help protect the environment.					
30. It is important to protect the environment even if it slows economic development.					
31. My actions have an impact on environment.					
32. The quality of life in my community depends on environmental conservation.					

Risk aversion

To what extent do you see yourself as a person characterised by: [1=: No risk aversion; 2= Low risk aversion; 3= Moderate risk aversion; 4= High risk aversion; 5= Very high risk aversion]

	1	2	3	4	5
33. General risk aversion;					
34. Risk aversion when it comes to your personal health;					
35. Risk aversion in the context of financial matters;					
36. Risk aversion when it comes to your farm and farming methods?					

8.5.3 *Survey descriptives – overall results*

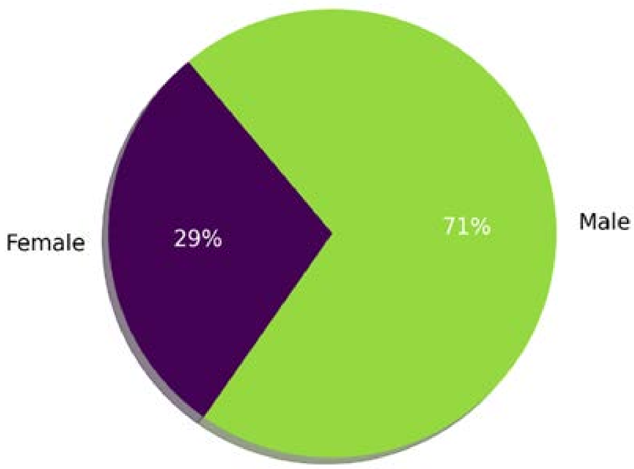

Figure 15. Gender distribution

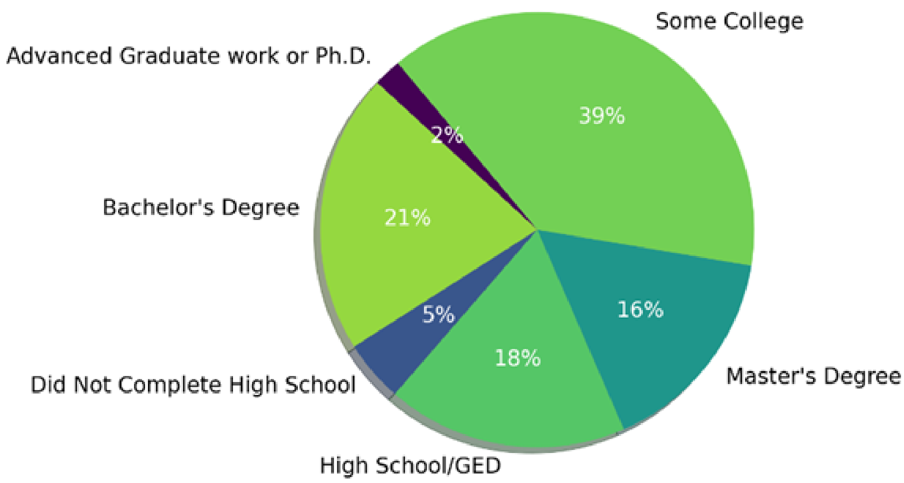

Figure 16. Education level distribution

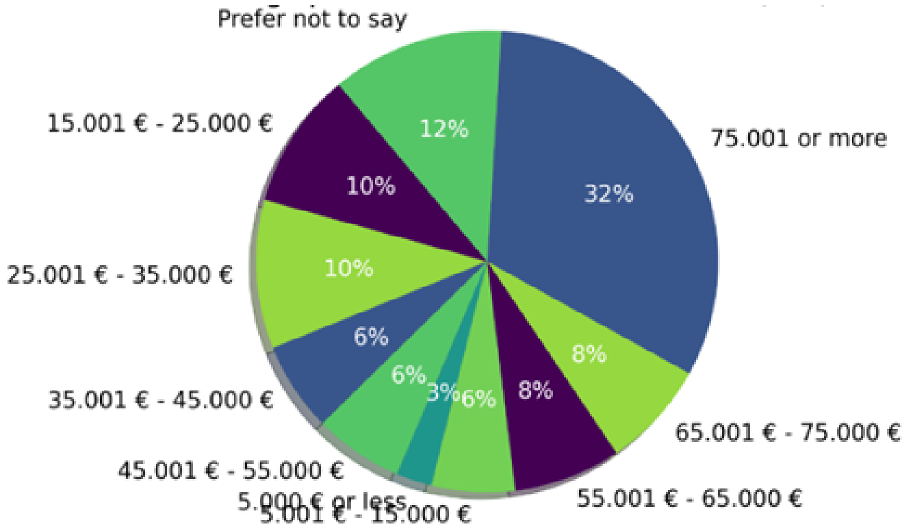

Figure 17. Annual household distribution (in €)

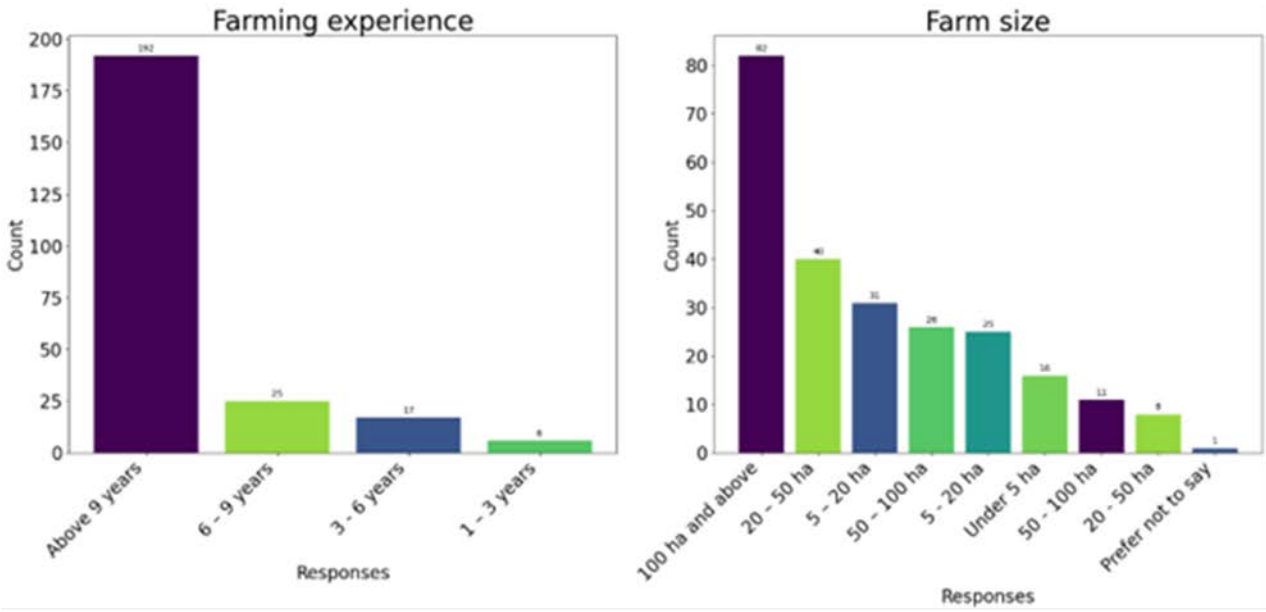

Figure 18. Distribution of farming experience and farm size

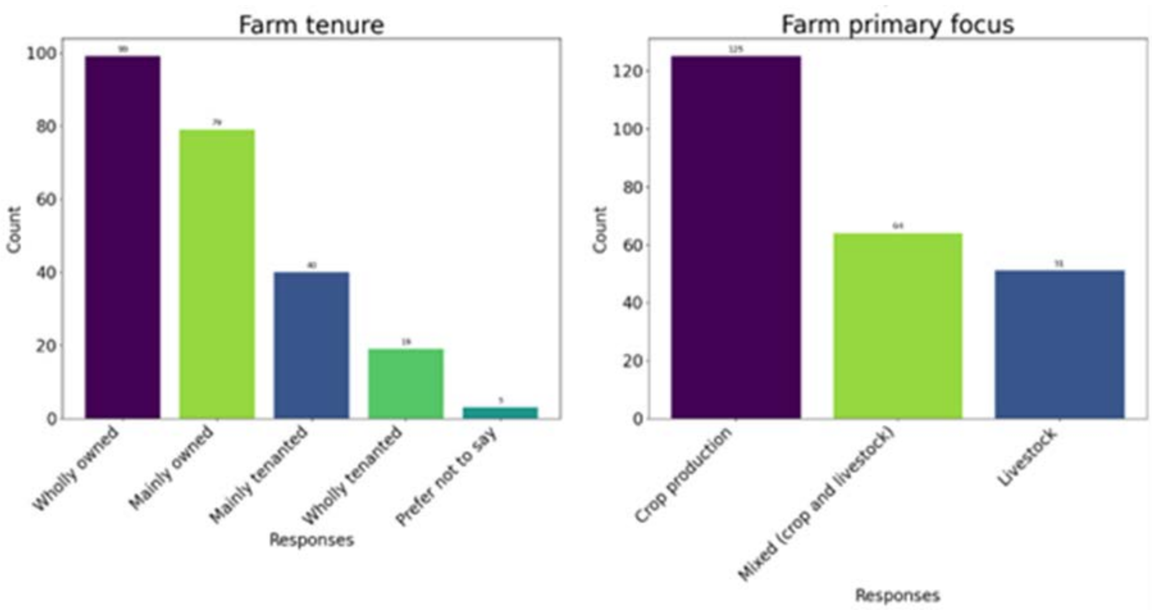

Figure 19. Distribution of farm tenure and primary focus

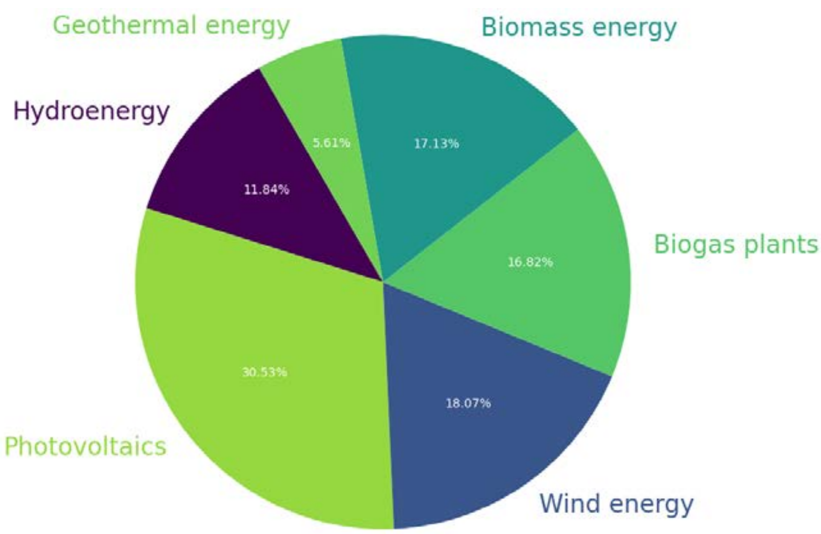

Figure 20. Renewable energy installations in local communities

8.5.4 *Survey descriptives results per UC country*

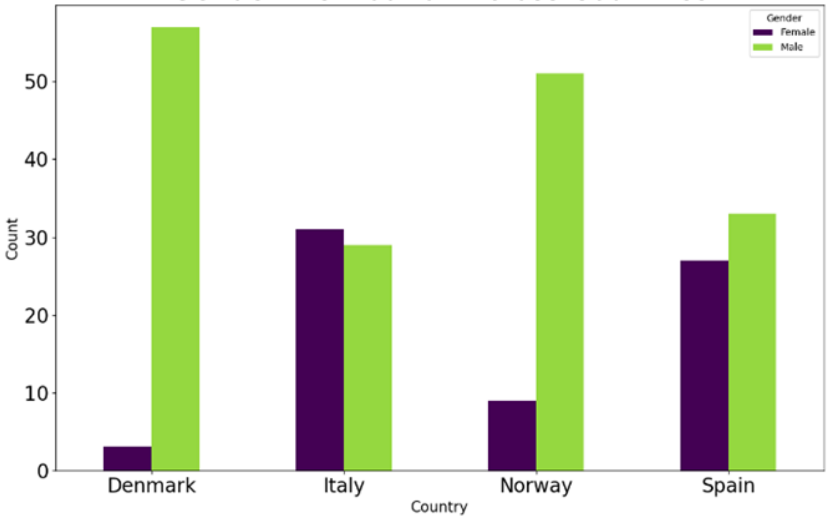

Figure 21. Gender distribution across countries

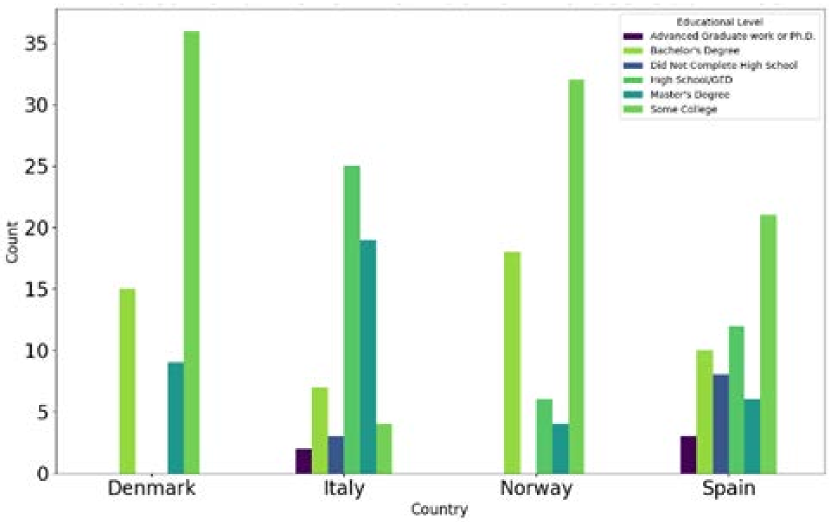

Figure 22. Educational level distribution across countries

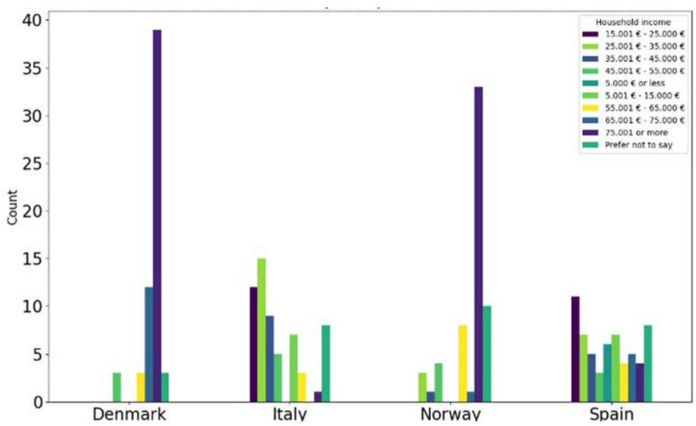

Figure 23. Annual household income (€) distribution across countries

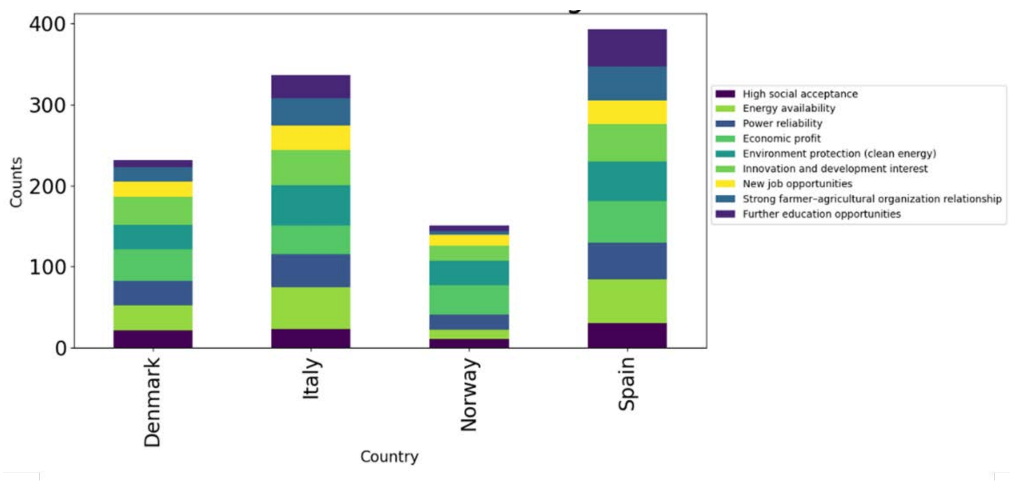

Figure 24. Potential barriers to establishing a RES

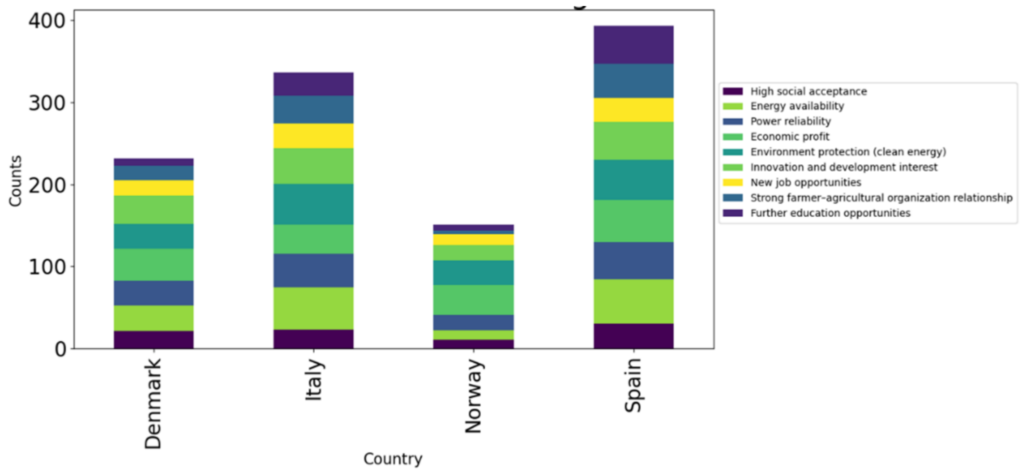

Figure 25. Potential drivers for establishing a RES

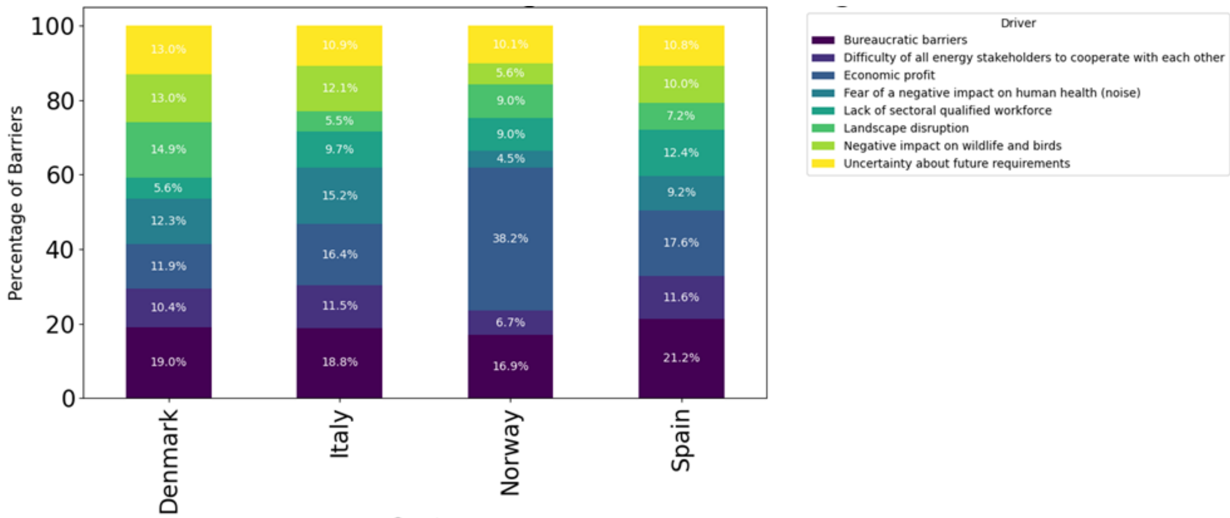

Figure 26. Potential barriers for establishing a RES (percentage)

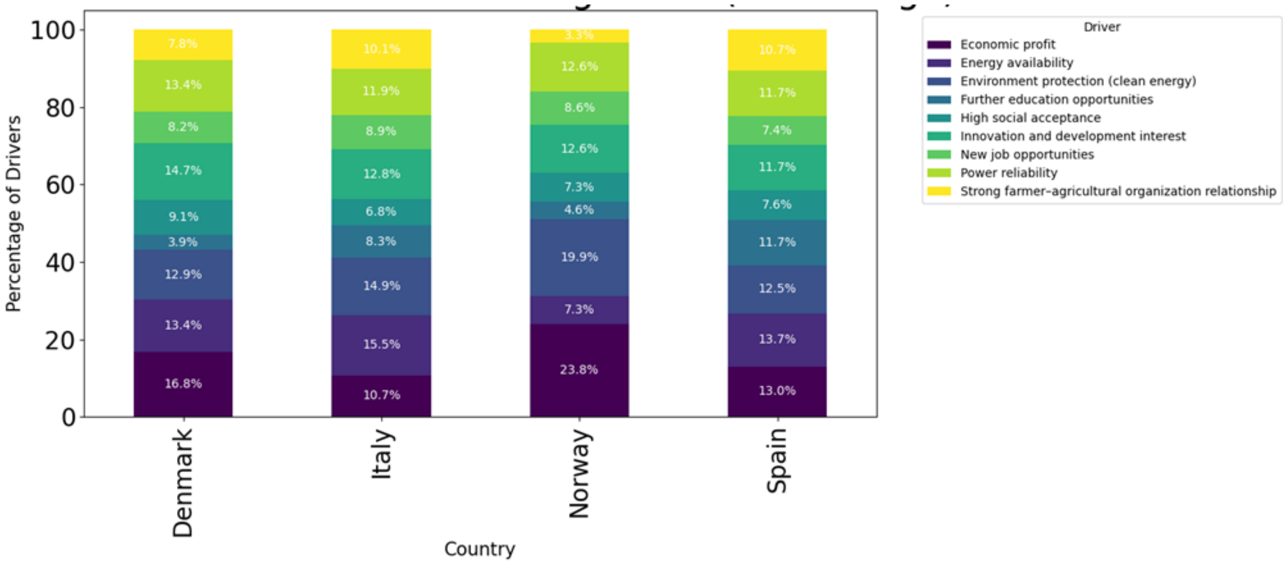

Figure 27. Potential drivers for establishing a RES (percentage)

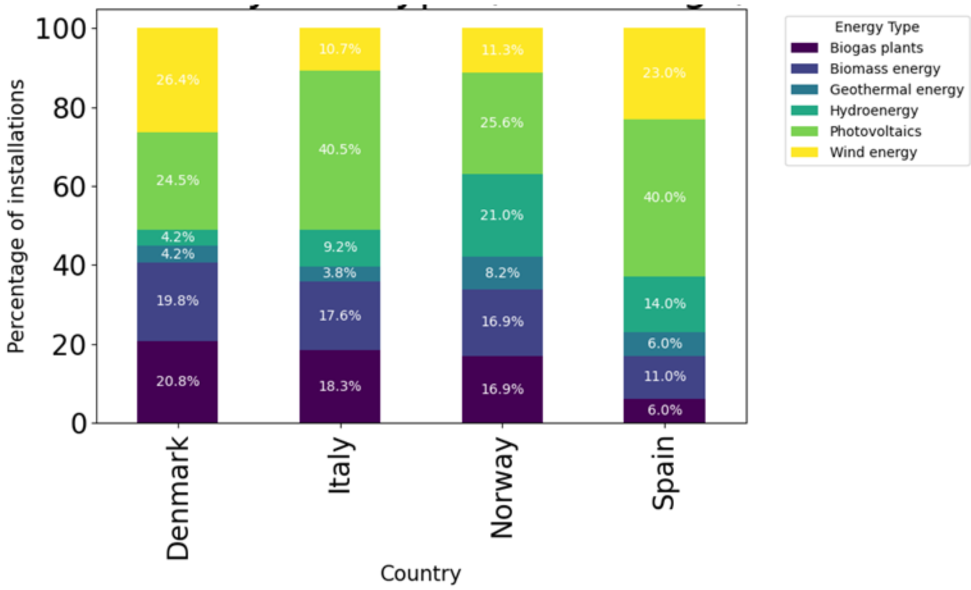

Figure 28. Energy installations by country and type (percentage)

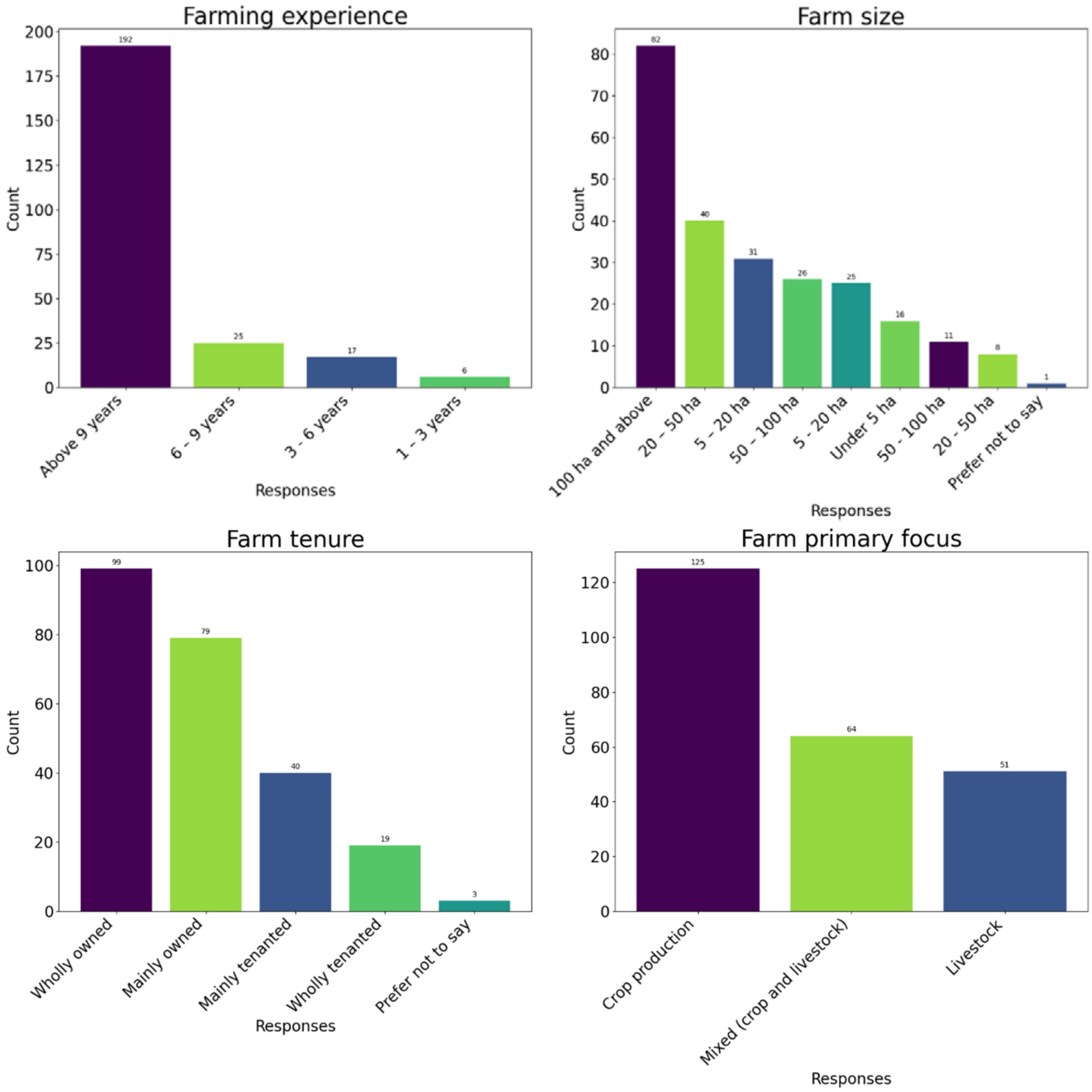

Figure 29. Distribution by country of farming experience, farm size, farm tenure and farm primary focus

Figure 30. Communication channels used to obtain information regarding new technologies

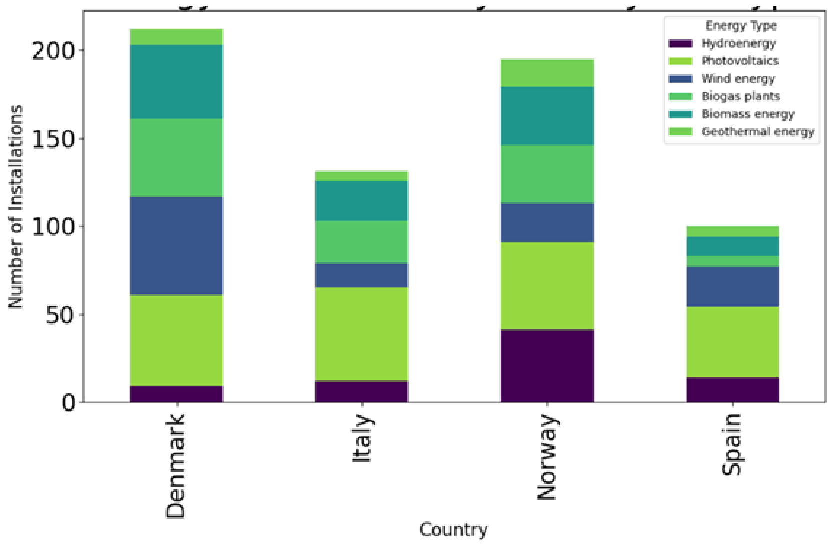

Figure 31. Energy installations by country and type

8.5.5 *Survey Regression model results*

The results of the regression model are documented in Table 15. Generally, if the **p-value** is less than 0.05, the results are traditionally considered statistically significant, which means that the findings are unlikely to have occurred by chance alone, and there may be a real effect or difference. The **estimate** (also known as the regression coefficient) represents the direction and magnitude of the relationship between each IV and the dependent variable. In our case, we can see in bold two IVs, which are the income and D2, that appear to have a significant role. More specifically, the negative relationship between income and intention suggests that higher income significantly decreases the intention to adopt RES, while the positive relationship between energy availability (D2) and intention, suggests that having high energy availability increases the intention.

Table 15. Regression model results

Dependent variable	Independent variables	Estimate	P
Intention	Country	-0.05165	0.364
	Gender	0.15513	0.257
	Age	-0.00714	0.316
	Education level	0.04231	0.364
	Income	**-0.05679**	**0.003**
	Farming experience	-0.07702	0.397
	Farm size	-0.05387	0.054
	Energy availability (D2)	**0.65279**	**0.005**
	Power reliability (D3)	0.16077	0.381
	Economic profit (D4)	-0.08160	0.719
	Environment protection (clean energy) (D5)	-0.37745	0.168
	Innovation and development interest (D6)	0.32711	0.332
	New job opportunities (D7)	0.34421	0.276
	Strong farmer–agricultural organisation relationship (D8)	0.19818	0.402
	Further education opportunities (D9)	0.03055	0.904
	Financial barriers (high interest rates, low farmer income, high maintenance/installation costs) (B2)	-0.05519	0.796
	Difficulty of all energy stakeholders to cooperate with each other (B3)	-0.12017	0.510
	Lack of sectoral qualified workforce (B4)	-0.01880	0.932
	Economic profit (B5)	-0.00620	0.978
	Bureaucratic barriers (B6)	-0.30482	0.192
	Fear of a negative impact on human health (noise) (B7)	-0.33073	0.236
	Landscape disruption (B8)	0.18724	0.537
	Negative impact on wildlife and birds (B9)	0.06330	0.907

Table 16. Path analysis statistically significant results

Type	Effect	Estimate	p-value
Indirect	Economic-interest Attitude ⇒ Intention	-0.05450	0.067
	Economic-interest PEU ⇒ Intention	0.01334	0.271
	Economic-interest PU ⇒ Intention	0.03491	0.100
	Environmental-stewardship Attitude ⇒ Intention	0.16915	<.001
	Environmental-stewardship PEU ⇒ Intention	0.09601	0.007
	Environmental-stewardship PU ⇒ Intention	0.14167	<.001
	Risk-aversion Attitude ⇒ Intention	0.13537	<.001
	Risk-aversion PEU ⇒ Intention	-0.05211	0.015
	Risk-aversion PU ⇒ Intention	-0.02077	0.287
	Economic-interest PEU ⇒ Attitude ⇒ Intention	0.00868	0.263
	Economic-interest PU ⇒ Attitude ⇒ Intention	0.02903	0.091
	Environmental-stewardship PEU ⇒ Attitude ⇒ Intention	0.06247	0.002
	Environmental-stewardship PU ⇒ Attitude ⇒ Intention	0.11780	<.001
	Risk-aversion PEU ⇒ Attitude ⇒ Intention	-0.03390	0.007
	Risk-aversion PU ⇒ Attitude ⇒ Intention	-0.01727	0.283
Direct	Economic-interest Attitude	-0.08239	0.061
	Attitude Intention	0.66147	<.001
	Economic-interest PEU	0.08549	0.233
	PEU Intention	0.15604	0.005
	Economic-interest PU	0.13608	0.077
	PU Intention	0.25651	<.001
	Environmental-stewardship Attitude	0.25572	<.001
	Environmental-stewardship PEU	0.61530	<.001
	Environmental-stewardship PU	0.55232	<.001
	Risk-aversion Attitude	0.20465	<.001
	Risk-aversion PEU	-0.33397	<.001
	Risk-aversion PU	-0.08096	0.274
	PEU Attitude	0.15348	<.001
	PU Attitude	0.32245	<.001
	Economic-interest Intention	-0.01753	0.749
	Environmental-stewardship Intention	0.01079	0.869
	Risk-aversion Intention	-0.00901	0.874
Total	Economic-interest Intention	0.01392	0.857
	Environmental-stewardship Intention	0.59790	<.001
	Risk-aversion Intention	0.00231	0.975

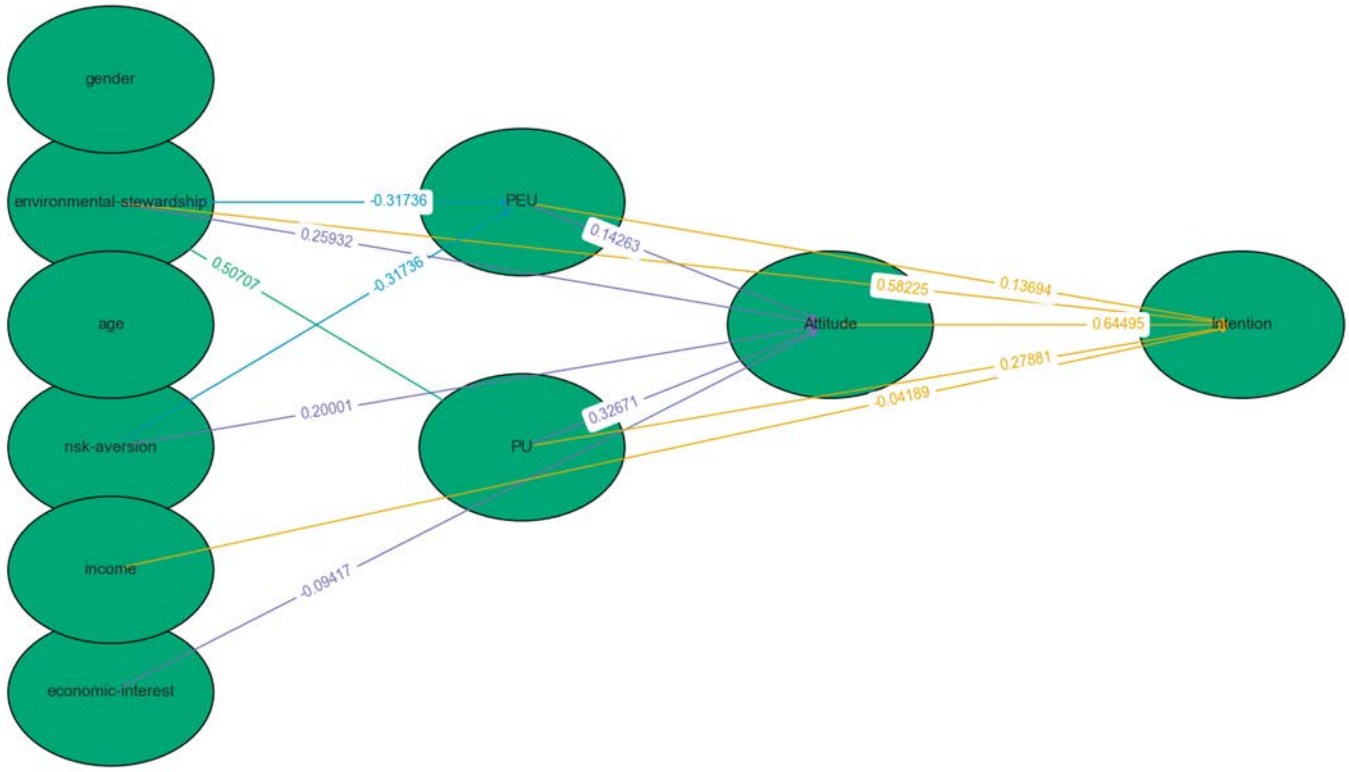

Figure 32. Path diagram for extended TAM model results including age, gender, and income

8.6 Annex 6: Detailed Summary

The HarvRESt project aims to integrate Renewable Energy Sources (RES) into agricultural systems, addressing environmental and economic challenges in the farming sector. The deliverable focuses on three tasks: identifying best practices for RES integration at the farm level, investigating framework conditions and stakeholder needs related to RES integration within specific use cases in Italy, Spain, Denmark, and Norway, and characterizing the specific needs and energy demands of each Use Case in the HarvRESt project. This report (Deliverable 2.1) aims to present the methods, the results and the conclusions of the three associated task of the HarvRESt project mentioned above. More specifically, Task 2.1: Mapping of best practices and existing initiatives on farm decarbonisation, Task 2.2: Assessment of the needs of local stakeholders and the framework conditions in the national and regional contexts of the HarvREST Use Cases, as well as at the EU level, and Task 2.3: Characterisation of HarvREST use cases through a multi-actor approach.

This report emphasizes the need for a systemic approach that considers environmental, economic, and social dimensions. The success of RES integration at the farm level depends not only on technological advancements but also on the alignment of policies, farmer engagement, and the adaptability of farming practices. Biomass energy production and agrivoltaics stand out as two of the most advanced technologies in the agricultural context, offering substantial benefits for farms.

In Task 2.1 it is evident that the strategic placement of RES infrastructure, such as wind turbines or solar panels, can mitigate potential trade-offs and even contribute to biodiversity preservation. But the interplay between climate change, energy, environment, biodiversity, food security, food safety, and agricultural production is complex and multifaceted. Climate change impacts agricultural productivity and food security, necessitating resilient and sustainable farming practices. Renewable energy integration at the farm level, such as solar panels and biogas production, can reduce greenhouse gas emissions and enhance environmental sustainability. However, the expansion of energy infrastructure must be managed to avoid biodiversity loss and ecosystem disruption. Land use changes play a significant role in this nexus, with conversion of natural habitats into agricultural land leading to biodiversity loss. Implementing practices like agroforestry and maintaining buffer zones around natural habitats can mitigate these impacts while supporting biodiversity. The use of marginal lands for renewable energy installations, such as solar panels on degraded lands, can prevent competition with agricultural production.

To achieve optimal integration of RES at the farm level, it is essential to consider broader aspects beyond immediate farm operations. Stakeholder engagement, innovative business models, and creative financing mechanisms can help address potential trade-offs and synergies within the environment, renewable energy, and agricultural production interplay. The integration of RES in agriculture impacts multiple interconnected systems, including the farm itself, local society, economy, food safety, food security, local ecosystems, biodiversity, and the broader environment. Key factors influence successful integration, including the level of application across farm operations, availability of energy storage systems, robust energy management systems, operational practices, logistics, and behaviors.

Task 2.1 explore the best practices for integration of solar, wind, biomass, hydro and geothermal power in the agriculture sector. The integration of solar power in agriculture faces numerous challenges, including technical, policy, land-use, financial, and societal issues. These include shading from solar panels, suitable farm infrastructure, policy-wise lack of clear definitions and regulations, fluctuating electricity prices, and difficulty storing large amounts of generated energy. Opportunities for solar power integration include market initiatives like Green Energy Certificates and "feed-in tariffs," and improvements in energy efficiency.

Good practices for implementing solar power in agriculture include engaging communities, involving stakeholders in site selection and planning, continuous monitoring post-implementation and using advanced technologies like solar-powered nodes, drones, and monitoring systems. Furthermore, The Bellegarde project in France is presented that exemplifies successful integration between renewable energy and agriculture by combining traditional arboriculture practices with high-mounted Agri-photovoltaic panels.

Wind energy is gaining significant attention in the agricultural sector, with technologies such as large-scale wind turbines, small wind systems, and hybrid systems combining wind and solar power offering numerous applications. However, the integration of wind energy faces challenges such as financial barriers, social acceptance, location suitability, technical challenges, and stakeholder engagement. Despite these challenges, there are significant opportunities for integrating wind energy into agriculture, such as providing a stable source of extra revenue for farmers, reducing dependency on external power sources, and exploring innovative applications like islanded microgrids for water pumps and desalination systems.

Combining wind and solar energy systems can enhance overall energy production and reliability, particularly in controlled agricultural environments. Good practices for implementing wind energy in agriculture include ensuring proper site assessment, understanding microclimate effects, integrating wind turbines with grazing, optimizing energy production through wind-PV hybrid systems, engaging local communities, and forming cooperatives. External investors can help cover initial costs, making wind energy projects more accessible for farmers, and ensuring ongoing monitoring and maintenance of wind installations.

Biomass-based energy technologies in agriculture have gained significant attention due to the growing emphasis on sustainability and mitigating climate change effects. Solutions related to agricultural biomass include biogas, biopower generation, bio-heat, biofuels, and biomass pyrolysis by-products like biochar. Different biomass feedstock types, such as energy crops, agricultural crop residues, forestry residues, algae, wood processing residues, and water wastes, can have a positive net impact on agriculture production and the climate.

The integration of biomass energy in agriculture presents several challenges, including logistical hurdles, financial barriers, and complexity in navigating policy and regulatory frameworks. However, biomass exploitation offers opportunities for diversifying revenue streams, enhancing economic resilience, and promoting a circular economy. Regional-scale business models and collective approaches, such as Combined Heat and Power schemes, can unlock scalability and foster community engagement. Good practices for successful biomass energy integration include engaging cooperatives and external investors, monitoring and managing robust waste and biomass, and being vigilant about potential trade-offs. Prioritizing agricultural waste and residues over primary biomass is often recommended. The LIFE SMART AgroMobility Project in Spain addresses the environmental and operational challenges of intensive pig farming by converting livestock waste into biomethane for agricultural vehicles and biofertilizers and it is worth mentioning and studied.

Integrating hydropower into agricultural systems presents several challenges, including balancing water use for irrigation and power generation. Careful management is needed to optimize the use of water resources for both agricultural and energy needs. Hydropower and geothermal energy are two emerging technologies in agriculture that offer potential for sustainable and economic growth. Hydropower, which uses existing irrigation systems and water infrastructure, can be integrated with existing water use without the need for new legal water rights. Pump as Turbines (PATs) technology and elevated water reservoirs can also be used to generate electricity.

Geothermal energy is increasingly used for agricultural operations, such as soil heating and greenhouse operations. It can reduce energy costs and reliance on traditional heating methods.Good practices for implementing geothermal energy in agriculture include considering technical, environmental, and socio-economic factors. Innovative governing models and leveraging geothermal energy for heating pumps and irrigation systems can optimize energy utilization and enhance agricultural productivity. Geothermal integration at Geothermiki Hellas Farm in Greece is an example of successful integration of geothermal energy into agricultural practices.

The integration of RES at the farm level can be facilitated even further by several cross-cutting best practices. These include education and training for all RES types and farm types, comprehensive stakeholder engagement during site selection and planning and conducting thorough assessments of site conditions, resource availability, and technology suitability. Combining different renewable energy sources, such as wind-PV hybrid systems or biogas and solar power, provides a more stable and reliable energy supply suitable for diverse farm types.

Improving energy storage capacities on farms is crucial for maximizing the benefits of renewable energy. Advanced battery storage systems, thermal energy storage, and hydrogen storage technologies enable clean energy storage and utilization, enhancing overall energy efficiency and resilience on the farm.

A holistic approach to energy efficiency is essential to avoid the potential rebound effect associated with the substitution of high emission or high pollution technologies with "clean" technologies. Efficient maintenance and optimized use of agricultural machinery and vehicles can support farm energy efficiency. Key best practices include precision agriculture techniques, precision livestock farming, conservation agriculture, adopting less input-demanding crop varieties and animal breeds, reducing water demand and losses, and ensuring energy-efficient fertilizer and machinery manufacture.

The promotion of circular/bioeconomy practices, carbon sequestration, and greenhouse gas (GHG) emission reduction is crucial for enhancing farm operations. By integrating soil carbon sequestration and GHG emission reduction, holistic approaches to farm decarbonation and climate resilience can be supported. Practices that enhance soil carbon sequestration at the farm level include crop rotation, soil coverage, no/minimum tillage, nutrient management, and crop diversification. The use of RES integration by-products such as biochar is also very relevant. RES integration at the level of the community, the region, or the landscape is also crucial. RES integration can be a key lever for rural development, as part of "place-based" innovation initiatives where farmers and neighboring stakeholders work together to share the benefits of RES infrastructure.

In conclusion, RES integration should be part of integrated approaches to transforming food and energy systems. Integrated food-energy systems (IFES) can contribute to the optimization of land use, including through the combination of mixed-cropping systems, agri-voltaic solutions, and biomass use through cascading uses of manure and other food chain residues.

Task 2.2 assesses the needs of local stakeholders in each use case (UC) and aims to understand the framework conditions in the national and regional contexts of HarvREStUCs, as well as at the EU level. The analysis is based on desk research results collected at both the EU and UC levels, as well as additional knowledge gained through interviews with regional stakeholders in each UC and a telephone survey conducted among farmers in each UC country.

Task 2.2 contributes significantly to the overall project by enhancing the understanding of public perceptions and exploring the social acceptability of renewable energy projects among farmers and rural communities. In task 2.2 employed a blend of methodological approaches to collect input from both primary and secondary sources. Data triangulation enhanced the reliability and comprehensiveness of the results. The first phase involved targeted desk research to gather information on existing framework conditions for renewables integration at the farm level across Europe. The second phase involved running a survey based on the desk research findings and a literature review to identify relevant gaps, targeting the five Use Cases. The third phase included interviews targeting regional stakeholders from various sectors, including industry, farmers, local authorities, and energy communities/associations.

This study aimed to collect data on farmers' intentions to adopt RES on their farms, identifying key knowledge gaps and perceived needs and challenges. The survey was conducted using the Computer-Assisted Telephone Interviewing (CATI) method, reaching rural areas with limited internet access and reducing errors. Data was gathered from key variables such as intention, attitude, perceived ease of use, and perceived usefulness based on TAM (Technology Acceptance Model), economic interest, environmental stewardship, and risk aversion.

The EU framework conditions and perceived needs at the EU level were also examined. The adoption of RES by farmers in Europe is critical for meeting the ambitious climate and energy targets set by the EU. Agriculture holds substantial technical and economic potential for both producing and utilising renewable energy. Despite the economic opportunities presented by renewable energy production, scaling up their uptake in the agricultural sector faces multifaceted challenges stemming from diverse natural, managerial, geographical, and socio-economic factors. Addressing these challenges requires sound advice, investment support, and risk management to facilitate farmer participation in renewable energy initiatives.

Socio-economic factors significantly influence farmers' adoption of renewable energy sources (RES) at the farm level. These factors include farming experience, farm size, main occupation, age, gender, marital status, and education level. Cognitive factors like education are particularly impactful, while contextual factors like socio-demographic profiles and local knowledge systems shape farmers' climate change adaptation strategies. Indigenous knowledge and traditional knowledge are crucial in Europe, and reimagining traditional methods through agroecology and RES could address sustainability challenges. Social networks also influence RES uptake, with interactions within these networks shaping awareness and willingness to adopt RES. Policymakers need to employ both economic incentives and behavioral interventions to encourage sustainable practice adoption. Education and experience are also important factors affecting farmers' adoption behavior, with prioritizing environmental objectives over social or economic ones. Balancing financial support with networking and knowledge dissemination among farmers is crucial for promoting sustainable practices.

The legal framework and political environment within which farmers operate play a crucial role in shaping their decisions regarding the adoption of RES options. Legal regulations, policies, incentives, and government support programs directly influence the feasibility, accessibility, and attractiveness of RES options for farmers. The Common Agricultural Policy (CAP) significantly influences farmers' decisions regarding the adoption of energy crops and technologies for renewable energy production in the coming years. Political agendas and priorities regarding energy and environmental issues can either facilitate or hinder the uptake of RE initiatives in the agricultural sector.

The uptake of RES by farmers in Europe is influenced by various legal and political factors. Supportive government policies and financial incentives are crucial. Direct payments and tax reduction schemes from public institutions promote investments in emission reduction solutions and align with EU policies, particularly within the CAP. Interventions addressing climate change mitigation and adaptation further support farmers' decisions to adopt innovative technologies. Government initiatives like the Farm to Fork strategy highlight the importance of support for a just transition towards sustainable agriculture.

However, several legal and political barriers hinder RES adoption among farmers. Planning and zoning restrictions, regulatory uncertainties, and grid infrastructure inadequacies hinder renewable energy deployment. Addressing these challenges requires coherent policy frameworks that align renewable energy objectives with broader rural development goals and promote synergies across policy sectors.

Moreover, the study aimed to analyse farmers' intention to adopt RES in four European Union countries and the 5 use cases. The data was collected through a comprehensive process, including data cleaning, preprocessing, new feature extraction, EDA, visualisations, descriptives, regression model, and path analysis. The majority of participants were males, with high annual incomes and college education. Most had over 9 years of farming experience and owned their farms. Barriers to establishing a RES included negative impacts on wildlife and birds and financial costs. However, environmental protection, clean energy, economic profit, and energy availability were perceived drivers.

The most common renewable energy technologies in local communities were photovoltaics (30.53%), followed by wind energy (18.07%), and biomass energy (17.13%). Farmers preferred communication channels to acquire information about new technologies, with peer networks being the most preferred. Cooperatives and associations were the second most preferred channel, acting as intermediaries to bridge the gap between individual farmers and broader technological advancements. Independent experts were the third preferred source of information, providing specialized knowledge and impartial advice. The study highlights the importance of farmer networks and communities in facilitating knowledge exchange and adoption of new technologies.

The study used a regression model to infer intention (dependent variable) from a set of independent variables (IVs) containing basic demographics and drivers and barriers in adopting RES. Results showed that income and energy availability significantly influence RES adoption. Higher income significantly decreases the intention to adopt RES, while higher renewable energy availability increases the intention. Farm size also affected the intention to adopt RES on farms, albeit to a lesser degree. Farmers with smaller farms demonstrated a greater willingness to adopt new technologies compared to those with larger farms. This can be strategically interpreted to enhance RES uptake across the agricultural sector.

The path analysis revealed that both environmental stewardship and risk aversion significantly influenced the intention to adopt RES, while economic interest did not show a statistically significant effect. Environmental stewardship is the primary driver for adopting RES in the agricultural sector, with sustainability concerns playing a significant role in shaping attitudes toward new technologies. Risk aversion has an indirect influence on adoption intentions, suggesting that strategies to mitigate perceived risks could effectively enhance RES uptake. Interestingly, economic interest was not found to be a significant driver, even when controlling for demographic variables such as income, education, and gender. This consistency highlights that environmental concerns and perceived technology attributes outweigh demographic differences in driving RES adoption.

The framework conditions and factors affecting RES uptake at farms in the UC countries are discussed, including the results of desk research and interviews with key stakeholders. Italy has made significant strides in renewable energy adoption, reaching its 2020 renewable energy consumption target of 17% in 2014 and renewable energy generation reaching 40.5% in 2021.

Socio-economic factors such as farmer age, education, farm size, and labor intensity significantly influence the adoption of RES among Italian farmers. Younger, educated farmers with larger operations show greater readiness to adopt RES technologies, driven by efficiency gains and labor savings. Economic considerations are paramount, with income levels, financial incentives, and cost-efficiency playing significant roles.

Policies like feed-in-tariffs and fiscal incentives significantly impact adoption rates by reducing the financial burden of installation and operation.

Italy faces significant challenges in its energy landscape due to its heavy dependence on imported coal, oil, and natural gas, exposing the country to price volatility and geopolitical risks. Initiatives like Green Certificate Systems and the Remuneration of Renewable Energy Resources (REM) aim to spur growth but require infrastructure improvements and government support. Political uncertainty, high initial costs, and bureaucratic hurdles hinder investment. Italy has implemented incentives to foster renewable energy adoption in its energy market, including Feed-in Tariffs (FIT) for smaller plants and Feed-in Premiums (FIP) for larger ones. Stakeholder needs include farmers seeking economically viable renewable energy solutions, energy communities seeking collaboration with farmers, and agricultural associations advocating for increased awareness and education on renewable energy adoption. These factors highlight the need for stable policies and streamlined regulatory processes to attract long-term financing and foster innovation in national agricultural activities.

The Danish HarvRESt UC focuses on the integration of RES technologies at the farm level, which is crucial for achieving Denmark's environmental and energy targets. Socio-economic factors influence the adoption of RES technologies, including economic barriers and social dynamics. Awareness and understanding of RES technologies among farmers and the wider community significantly impact their adoption rate. Educational programs and social acceptance are essential for overcoming skepticism and fostering a supportive community environment. Successful projects often involve early and transparent communication with the community, addressing potential concerns related to noise, smell, and landscape changes. Financial accessibility is crucial for farm-level operators, with the Danish Green Investment Fund providing tailored loans and grants that cover up to 60% of the initial investment needed for RES projects. Market-based incentives, such as feed-in tariffs and RE certificates, can also promote RES integration. The average payback period for RES investments in Denmark ranges from 5 to 15 years, depending on the project scale and efficiency.

The adoption of RES on farms in Denmark is influenced by a complex interplay of legal and political factors. Denmark has implemented financial incentives, such as subsidies, tax breaks, and tailored grants, to facilitate RES adoption. The Danish legal framework supports RES integration with clear guidelines for project development, grid connection, and operation, simplifying decision-making for farmers and investors. However, navigating administrative processes, environmental standards, and grid connectivity requirements across municipalities can be challenging and inconsistent. Denmark's national energy strategy prioritizes RES over fossil fuels, aligning with ambitious carbon reduction and RE targets. Local governments complement these efforts with additional supports tailored to regional conditions, fostering community engagement and investment in RES projects.

Legal and political factors affecting the uptake of RES at the Danish UC include government policies, regulatory clarity, legislative inconsistencies, and regional and local initiatives. Stakeholder needs and perceived challenges include farmers, energy communities, agricultural associations, public authorities, and medium-sized energy industries. Farmers require extensive technical support and knowledge transfer to optimize the integration and operation of biogas systems on their farms, while energy communities need effective collaboration platforms to manage joint biogas projects and access broader energy markets.

Agricultural associations play a crucial role in advocating for more supportive policies from the government, including enhancements to existing subsidies and incentives. Public authorities have a mandate to meet sustainability targets and promote local energy security. Medium-sized energy industries require strategies that integrate biogas into their energy mix effectively, ensuring stability and reliability in supply.

In Spain, the integration of RES into agricultural activities presents both economic opportunities and challenges. Initial investments in RES infrastructure require careful consideration of financing options and return on investment, crucial for ensuring the viability and sustainability of these projects. Economic benefits include energy bill savings and income generation from selling surplus energy, motivating widespread adoption among farmers. However, it is imperative that these installations do not compromise agricultural productivity over the long term, necessitating robust planning and management strategies to mitigate potential impacts on land use and crop health.

The integration of RES into farming practices is increasingly relevant due to its potential for energy security, cost savings, and compliance with national and European regulations. In Spain, initiatives like Law 7/2021 on climate change and energy transition and the Strategic Plan of the CAP (PEPAC) aim to mitigate climate impacts and enhance energy self-sufficiency in agriculture. Legislative measures such as Royal Decree 244/2019 and Law 24/2013 simplify administrative processes and support RE adoption among agricultural producers, fostering Spain's transition towards a decarbonised energy sector.

Legal and political factors affecting the uptake of RES at the Spanish UC include the EU Solar Energy Strategy (REPowerEU), legislative frameworks like Law 7/2021 on Climate Change and Energy Transition in Spain, lack of specific regulation in Spain, administrative and bureaucratic barriers, lack of clear definition, and legal structure governing self-consumption of electricity. Stakeholder needs and perceived challenges must be addressed to foster successful collaboration and implementation of RES.

Stakeholders emphasize the need for robust regulatory frameworks and incentives to support RES adoption. Collaboration between academic institutions and public authorities is vital in providing research and technical expertise. The existence of national and European directives pushing for decarbonisation in agriculture sets a favourable backdrop for these initiatives, but practical implementation often faces hurdles. Opportunities exist for integrating RES into farming practices, including pilot projects, demonstration sites, specific programs, and financial incentives.

Catalonia, Spain, has significant biogenic sources that can produce bioenergy, with agriculture and livestock playing a crucial role. A strategy is needed to promote the sustainable valorisation of livestock manure and organic waste through anaerobic digestion to produce biogas and high-quality organic fertilisers. This approach aims to achieve Catalonia's climate neutrality by 2050. Biogas presents a threefold opportunity: processing organic resources, reducing emissions from waste management, and generating renewable energy, thereby reducing fossil fuel emissions.

Socio-economic factors significantly affect the uptake of RES at farms in Spain. One major challenge is the lack of information about the availability and territorial distribution of organic materials. Efforts should focus on disseminating this information to businesses and the public, as well as fostering collaboration between the livestock sector, waste producers, and nearby biogas facilities to optimize organic waste utilisation for biogas production.

The adoption of RES on farms in Spain is influenced by the country's legal and political framework, which emphasizes biogas production and utilization. Key EU directives, such as RED III 2023/2413 and RED II 2018/2001, set integration targets across member states. Spain has enacted laws like Law 34/1998, which extends regulations for natural gas to include biogas and biomass-derived gases, facilitating their integration into the natural gas network. Royal Decrees (RD) play a crucial role in governing biogas infrastructure, ensuring compliance with quality and safety measures.

Key stakeholders in the agricultural sector, including farmers, energy communities, agricultural associations, public authorities, and medium large-sized energy industries, have specific needs concerning the uptake of RES at the farm level in Spain. They are primarily focused on reducing operational costs, enhancing energy security, and aligning with regulatory requirements aimed at reducing carbon emissions. Public authorities and medium-sized energy industries play a crucial role in creating an enabling environment for RES adoption through policies and incentives.

In Norway, hydroelectric power dominates electricity generation, accounting for 88% of total output. The Norwegian Agrarian Association aims to reduce GHG emissions in the agricultural sector by 4-6 million tons of CO_2-eq by 2030, with 10-25% expected from substituting fossil fuels with renewable energy sources.

The installation of RES on farms in Norway faces significant challenges due to the absence of established support schemes tailored for agricultural settings and a lack of plug-and-play solutions that integrate RES effectively into local farm energy systems. However, the imperative to address climate change impacts and rising energy costs has created increased interest in locally installed RES, which not only ensure reliable food production and supply but also reduce farms' vulnerability to energy market disruptions.

Socio-economic factors influencing RES adoption on farms highlight its potential to enhance community engagement, create new rural job opportunities, diversify income streams, optimize resource efficiency, and promote environmental stewardship. Government policies, incentives, and access to capital are pivotal in facilitating this transition, while education and awareness programs are crucial in empowering farmers with the knowledge needed to adopt and integrate RES effectively.

The Norwegian Parliament aims to ensure food security, sustain farming, foster value creation, and promote sustainable agricultural practices. RES adoption on farms must align with economic, social, and environmental considerations. Socio-economic factors affecting RES uptake include government policies, resource availability, technological advancements, market dynamics, community engagement, skilled labor, regulatory framework, and energy independence and resilience.

Norway's energy policies prioritize renewable energy through initiatives like the Renewable Energy Act, which establish targets and support mechanisms like green certificates. However, agricultural sectors like farms receive limited assistance, primarily through programs like BIONOVA, which funds bioenergy and climate initiatives. Additionally, national programs do not cover aspects like integrating different energy sources to match farm energy demand profiles.

Legal and political factors affecting RES uptake include lack of policy coordination, lack of policy awareness, limited schemes on specific technologies, financial support and incentives, and electricity price in Norway. These factors must be addressed to ensure the uptake of RES and promote sustainable agricultural practices. The Norwegian Parliament's agricultural policy frameworks must consider economic, social, and environmental factors to ensure food security and promote sustainable practices.

The current framework conditions show mixed readiness for renewable energy adoption on farms, with energy companies stressing the need for streamlined regulatory processes and better financial incentives. Farmers are aware of the environmental benefits but are often deterred by high initial investment costs and the complexity of integrating these systems into existing farm operations.

Opportunities include the growing awareness of climate change and the environmental benefits of renewable energy, technological advancements making RES more efficient and cost-effective, and potential for community-based renewable energy projects. Collaborative efforts between energy companies, public authorities, and farmers can create innovative solutions and build a more supportive ecosystem for renewable energy adoption.

The next part of this report (Task 2.3) focuses on characterizing HarvRESt use cases through a multi-actor approach, aiming to identify the main perceptions and objectives for each use case and collect necessary information for characterization. The project will be supported and executed at five use cases located in Italy, Denmark, Spain, and Norway, representing different topologies of farms, diverse stakeholders, geographical conditions, and a wide variety of renewable energy technologies.

The Italian use case involves agro-industrial, farmers, and industrial associations addressing RES integration at farm level along the entire agri-food value chain. The Danish use case uses existing datasets on RES production at farm level, with a special focus on biogas production. The main objectives are to enhance the Biogas planning tool as a comprehensive database at farm level for Denmark and map current activity levels and potentials for biogas fuelled energy production.

Spain use cases involve Viñas del Vero and Sorigué, two Spanish farming companies exploring decarbonisation strategies and deployment of renewable energy technologies in their farms. The key objective is to apply HarvRESt solutions to enhance production management and increase overall benefits with lower environmental impact.

Norway use case involves GGE and NORCE analyzing how to develop and expand a smart energy system that supports the full decarbonization process of GGE. The main objective is to manage the integration of the energy storage system interaction with different renewable assets and optimize available resources.

The Italian use case FATTORIA SOLIDALE DEL CIRCEO, an organic farm dedicated to social and agricultural inclusion and sustainability projects. The farm is located near the Tyrrhenian Sea in the Lazio region of Italy, experiencing a Mediterranean climate with mild winters and hot, dry summers.

The Circeo Area, a Mediterranean region, is home to various agricultural practices and activities, including olives, vegetables, fruits, and organic farming. FATTORIA SOLIDALE DEL CIRCEO uses organic production methods for crops like red lentils, fodder, zucchini, watermelon, romaine lettuce, and Romanesco broccoli. TThe farm is expected to expand by adding an agro-PV plant, with an area that has the potential to host a production capacity of 70 MW of photovoltaic energy. The farm's energy usage is currently around 20 kW, but this could increase to over 100 kW due to plans to install an electric irrigation system and additional equipment.

Data monitoring on the farm is limited, with automated sensors monitoring parameters such as light, temperature/humidity, and CO_2. Real-time energy monitoring is available through the inverter, but further development is needed to monitor environmental conditions and crop health. The digital infrastructure for data storage and analysis mainly consists of a laptop.

The Italian Use Case aims to explore new business models to increase interest in agricultural products with reduced carbon footprints and valorize farmers' social impact. Key Exploitable Results (KERs) include HarvRESt Agricultural Virtual Power Plant (AVPP), HarvRESt Decision support System (DSS), strategy for multiactor engagement, and business model catalogue. Tentative KPIs to consider include performance of assets, economic impact of agricultural production, social impact, and sustainability of agricultural practices.

In Denmark, the key stakeholders include farmers, agricultural organizations, biogas companies, organic producers, and regulatory bodies. The country's climate is influenced by its proximity to the sea, moderate precipitation, high humidity levels, and wind activity.

Denmark's agricultural sector is a significant contributor to the country's economy, with pig production being a major source of liquid manure. The country is a global leader in developing and producing equipment for managing animal manure as fertilizer, underpinning the robust biogas production sector. The agricultural landscape is divided into several soil types, including sandy loam, clay-enriched, and organogenic soils. In 2023, Danish agriculture utilized 2,669,356 hectares for various crops, using advanced agronomic practices like precision farming, integrated pest management, and crop rotation and soil management.

The Danish use case focuses on evaluating the potential for biomass utilization in the biogas industry, focusing on potential capabilities across various scales of biogas operations. The decision-making process does not require real-time data, allowing for a broad-based evaluation of biogas potentials that can scale across different sizes and types of biogas plants.

The expected outcomes of the Danish use case include an enhanced biogas planning tool, economic and environmental benefits, innovative business models, and scalability and policy recommendations. KPIs to consider include asset performance, optimization of biogas production, economic impact reduction, reduction in GHG emissions, and improvements in nutrient recovery and management.

The Spain Use Case (VdV-VRT) focuses on two key areas in two vineyards: Viñas del Vero, located in the Somontano DO region (Barbastro (Huesca)), is centered on the development of an efficient energy management system (EMS), while Viñedos del Río Tajo, situated in Toledo, focuses on assessing the impact of renewable energy sources (RES) on crops. The regions have ideal altitudes, climate, and soils for vine growing, with a Mediterranean climate with continental influences. The main crops in both areas are pink tomatoes, cereals, vegetables, and vines.

The use case aims to reduce electricity consumption in both areas, with Viñas del Vero's total electricity consumption being 1,413,164 kWh/year, while Viñedos del Rio Tajo's total consumption is around 939,000 kWh/year. Data monitoring and digitalization will be focused on monitoring an agrivoltaic pilot plant and the effects of partial vines shadowing on grape quality and crop growth and health at Viñedos del Rio Tajo.

In Viñedos del Rio Tajo, IoT technology will be used to continuously monitor vineyards, collect climate, plant, and soil data, optimize solar panel positions, and optimize machinery operation times. The HarvREST project will further expand and improve this setup, aiming to develop integrated energy management and electrify parts of the production chain that currently rely on fossil fuels.

The anticipated outcomes in the Viñas del Vero & Viñedos del Tajo use case include improved energy management systems, reduced energy consumption, and increased efficiency in the wine industry. The specific KPIs are yet to be precisely defined, but this outline serves as a preliminary framework that will evolve as the project progresses and the feasibility of various experiences becomes clearer.

Sorigué-Torre Santamaria is a partnership mainly dedicated to agro-technology providers and cow's farms in the Noguera Region (Balaguer, Catalonia). The region has a continental Mediterranean climate with cold winters and hot summers, with moderate precipitation. The main agricultural activities around the farm include corn cultivation, straw, and wheat.

The project aims to improve energy efficiency, increase self-consumption of renewable energy, and optimize the operation of electric agricultural machinery. The project will also contribute to the development of new technologies and practices for sustainable agriculture in the region.

Torre Santamaria, a farm with over 2,000 cows, consumes over 1,000,000 kWh of energy. The most consumptive equipment is the vacuum pump, cooling tank, and cleaning systems. Energy consumption varies between summer and winter, with winter being more energy-intensive for heating and lighting. The current waste management plant (biomethane plant) consumes 4,616,840 kWh/year, with a self-consumption rate of 38% due to the cogeneration system. All energy consumed comes from the electrical grid.

The SCADA system forms the backbone of data monitoring and control, providing essential insights into operational performance. The system can automate processes such as liquid or gas levels adjustment, biogas transfer, and injection flow regulation. Manual measurements are conducted to monitor biogas composition and activity levels.

The ACSA-Sorigué Use Case aims to improve data collection, nutrient recovery, circularity, and new methane production pathways. The main problem is managing the digestate and optimizing anaerobic digestion. The expected outcomes include collecting data from the biorefinery to model biogas production from agro-residues, assessing the fertilizer potential of nutrients recovered from the digestate, and analyzing methane production from recycled CO_2 sources.

KERs include KPIs for performance monitoring, soil quality methodology, biogas planning tool, HarvRESt AVPP, and HarvRESt DSS. Tentative KPIs to consider include a set of KPIs related to asset performance, optimization of biogas production, improvements in nutrient recovery and management, and soil health.

The farm, located 250 meters above sea level, has a temperate oceanic climate with mild winters, cool summers, and high levels of precipitation. The farm focuses on livestock farming, with an average of 20 cattle and 175 pigs. The cattle are grown locally and 50% from Japan, while the pigs are purchased at 70 kg and grown on the farm up to 115-130 kg. The farm consumes 400,000 kWh/year of electricity from the grid and 46,620 kWh from local PV panel production (2023). The primary energy consumption is for the butchery's heating, cooling, cleaning, and tool operation, followed by farm operations and building energy use.

The nearest power grid connection point is located on the farm, with a farm-owned transformer ensuring high reliability of the grid infrastructure. A renewable generation plant, consisting of large wind turbines, feeds energy directly into the grid without connecting to the farm's energy system. Backup power integrated in the microgrid is available through a 136 kW battery pack. Fossil fuels are used for the tractor, an excavator on the farm, three diesel-fuelled cars for the butchery, and two electric cars, one for the farm and one for the butchery.

Data monitoring on the farm includes demand data, PV generation, and battery capacity. Automatic data collection will involve automatic data collection via the Eco Store AS system, while a new higher-capacity battery pack will be installed during the project. IoT devices will control the EMS to manage the battery and reduce energy costs. KERs include HarvRESt smart energy system algorithms.

HarvREStGreener Farming with RES

The project

The HarvRESt project aims to enhance the sustainable production of renewable energy at farm-level. This approach not only makes farms climate-neutral but also optimizes production, reduces their impact on natural resources and biodiversity, and provides energy services to communities, thereby diversifying economic income. However, deciding how best to integrate renewable energy sources (RES) on a farm is not without its challenges. The decision is a complex one, with many factors to consider. Due to this, HarvREStseeks to identify, understand, and overcome the existing barriers hindering the widespread adoption of this innovative approach. Current initiatives often overlook the complex interactions and factors within the farming and RES context, resulting in ineffective support for decision-making based on accurate projections, estimations, and forecasts. HarvREStwill therefore consolidate and enhance existing knowledge, creating an Agricultural Virtual Power Plant capable of running diverse scenarios and farm configurations. This tool will determine the best operational procedures for a given RES solution, providing valuable data to a decision support system. This system will weigh trade-offs and key indicators, offering tailor-made recommendations to farmers and policymakers.

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	Viñas del Vero	VdV
	Viñedos del Rio Tajo	VRT
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