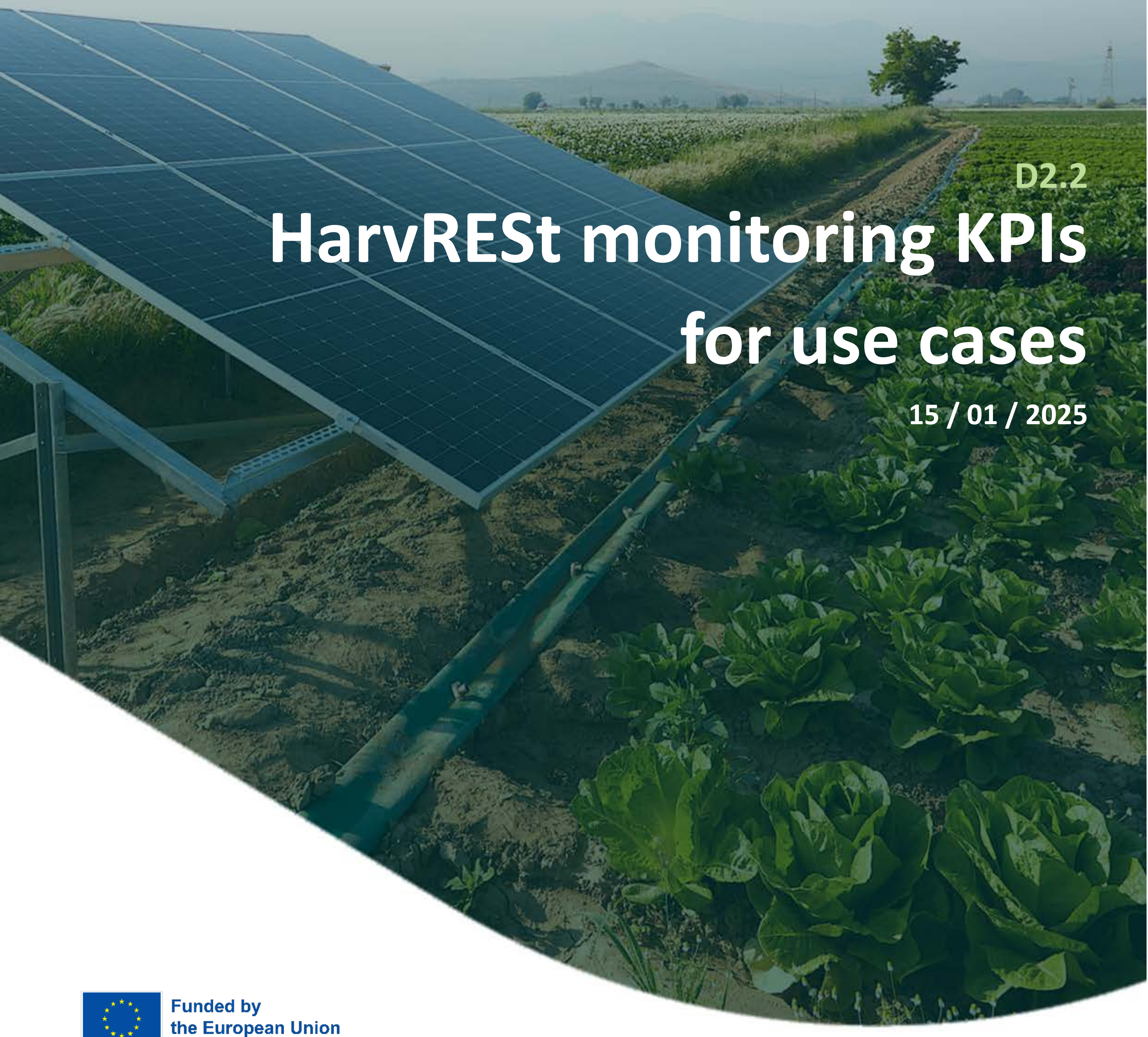

HarvREStt
Greener Farming with RES

D2.2

HarvREStt monitoring KPIs for use cases

15 / 01 / 2025

Funded by the European Union

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PROJECT INFORMATION

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1.0	15/01/2025	Final format changes	CIRCE

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ABBREVIATIONS

BaU	Business as Usual
BESS	Battery Energy Storage System
C	Carbon
CAP	Common Agricultural Policy
CAPEX	Capital Expenditures
CFA	Climate Farm Advisors
CFD	ClimateFarm Demo
CSF	Climate Smart Farming
D	Deliverable
DO	Denominación Origen (Spanish, denomination of origin in English)
DoA	Description of Action
DSS	Decision Support System
DST	Decision Support Tool
EC	European Commission
ETo	Evapotranspiration
EU	European Union
FAOSTAT	Food and Agriculture Organization Statistics
FEFTS	Fossil-Energy-Free Technologies and Strategies
GHG	Greenhouse Gas
ICT	Information and Communication Technology
IRR	Internal Return Rate
KPI	Key Performance Indicator
LAI	Leaf Area Index
LCOS	Levelized Cost of Storage
M	Month
NPK	Nitrogen, Phosphorus, Potassium
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational and Maintenance Costs
PDF	Pilot Demo Farmers
PV	Photovoltaic

RES	Renewable Energy Sources
RH	Relative Humidity
R&I	Research and Innovation
SA	Surface Area
SMART	Specific, Measurable, Attainable, Relevant, and Timely
SOC	Solid Organic Carbon
TBD	To Be Defined
TPAM	True Price Assessment Method
UC	Use Case

1. EXECUTIVE SUMMARY

This deliverable reports on the project's work related to the definition of KPIs and the analysis of their interaction. As a first part, it provides a foundational understanding of KPIs and outlines key considerations specific to agro communities for selecting appropriate indicators. These considerations emphasize the unique characteristics of agricultural operations, including environmental dependencies, social aspects and economic constraints. Furthermore, it conducts an extensive review of existing projects and initiatives in the same domain, leveraging insights to identify established KPIs and associated best practices. This groundwork ensures that the followed approach aligns with current advancements and addresses gaps in the measurement of RES integration in agricultural contexts.

Building upon this foundation, the second part commences by integrating findings from prior work inside HarvRESt which identified preliminary considerations related to Use Case outcomes. It expands on these insights to propose a comprehensive set of KPIs under five categories: agricultural, economic, energy, environmental, and social. These KPIs aim to holistically evaluate the performance and sustainability of the project's Use Cases, which include diverse farming operations. Each KPI is meticulously defined with a clear description, detailed measurement guidelines, including data requirements, calculation formulas, and applicable units, ensuring their practical applicability and reliability.

To further facilitate the assessment of the project's Use Cases, a traceability matrix is laid out, linking KPIs to specific Use Cases. This mapping identifies the relevance of each KPI to individual Use Cases, offering clarity on performance measurement at both granular and overarching levels. The deliverable seeks, as much as possible at this stage of the project, to ensure that the KPIs could yield insights beyond the specificities of each Use Case's context. To this end, considerations related to benchmarking the proposed KPIs against existing agro community data, is provided wherever possible, to provide a reference point for evaluating RES integration while maintaining comparability with external contexts.

Then, the deliverable outlines preliminary steps for data collection and pre-processing. These steps aim to standardise data gathering and enhance the robustness of KPI measurement across the five project Use Cases. By adopting this structured approach, we aim to develop a reliable ground for evaluating the integration of RES in agro communities; the work will be further evaluated in upcoming Work Packages, for example in order to understand trade-offs and to establish weighting criteria.

Finally, a conflict matrix has been developed in order to identify which KPIs have a critical effect in others.

2. INTRODUCTION

2.1 Purpose and structure of the document

The deliverable at hand is the output of Task 4.2 at month 12 of the project. In the deliverable, the consortium partners identify and comprise a list of KPIs to characterise and describe the performance of the project's Use Cases (i.e., the farms) from a production and sustainability point of view. The KPIs comprise energy, agricultural, environmental, economic and social aspects. The KPIs have been devised using information from several sources:

(a) the nature of the project's Use Cases,
(b) other known projects and initiatives (past or running),
(c) existing EC Monitoring Frameworks,
(d) the HarvREST Pillars as described in the project's DoA.

In the deliverable at hand, all proposed KPIs have been included and are currently considered as a preliminary list of KPIs to be calculated, monitored and assessed along the project duration. Each KPI has been mapped to one or more Use Cases, for which it is deemed relevant. In future work,]the initial list of KPIs could be reduced, if deemed necessary. For each selected KPI, a solid description has been provided, followed by detailed guidelines for their measurement, i.e., what data is needed, which is the calculation formula, and what is the unit in which the KPI is expressed.

In **section 3**, the methodology for selecting the right indicators is given and the review of known projects and initiatives (past or running) is presented.

In **section 4**, the Use Cases considerations from deliverable D2.1 are presented again, then enriched in order to define the list of KPIs; following this step, the mapping among KPIs and Use Cases is given in the form of a traceability matrix, and further considerations related to data collection, pre-processing and monitoring are laid out.

Section 5 concludes the present deliverable.

2.2 Connection with other tasks

The input for this task is the work done in Task 2.3, documented in deliverable D2.1 of HarvREST project. From this deliverable, the expected outcomes of the project's Use Cases were considered and enriched. As mentioned in section 2.1 above, the list of KPIs which is laid down in this deliverable is considered preliminary. The results of Task 2.4 and deliverable D2.4 in particular will feed into Task 4.2 "Developing KPIs to monitor the RES system", as well as Task 6.1 "Development of the Agricultural Virtual Power Plant". In those two tasks, the list of KPIs will be further evaluated, for example in order to understand trade-offs and to establish weighting criteria, and ultimately used.

3. FROM METRICS TO COMPREHENSIVE KPIs

About 30% of global energy is consumed by agri-food systems, with a significant portion—nearly a quarter—used during the production stage, contributing to a third of the sector's greenhouse gas (GHG) emissions. This highlights the urgent need to reduce energy consumption's environmental and economic impact in agriculture. Integrating Renewable Energy Sources (RES) can decarbonise and make farm production more sustainable. However, the complexity of balancing trade-offs, creating co-benefits, and addressing diverse stakeholder preferences complicates decision-making on RES adoption strategies.

Social acceptance is key, as agro communities comprise diverse groups, including smallholder farmers, cooperatives, and marginalised populations. Ensuring fair resource access, inclusive participation, and equitable benefits is essential to avoid resistance that can hinder the success of decarbonization efforts.

The HarvREStt project was designed to accelerate the adoption of RES technologies alongside sustainable farming practices, supporting the decarbonization of the agri-food sector. HarvREStt employs a holistic, multi-actor approach, addressing social, economic, environmental, technical, and regulatory considerations to balance stakeholder interests effectively. The project features diverse use cases in Italy, Denmark, Spain, and Norway, enabling co-creation, validation, and solution testing in real-world settings.

Key performance indicators (KPIs) play a crucial role in capturing the expected impacts of these efforts, facilitating qualitative and quantitative assessments. They enable agro communities to monitor progress, measure outcomes, and make informed decisions aligned with sustainability goals. Using KPIs helps evaluate specific targets and track advancement toward Sustainable Development Goals.

However, selecting the right indicators is challenging. It requires aligning high-level project objectives with the specifics of interventions and actions. Following best practices to define KPIs is essential, as these metrics form the foundation of monitoring and impact assessment frameworks. Through this structured approach, HarvREStt ensures effective measurement and actionable insights, driving meaningful progress toward sustainable agricultural transformation.

3.1 Definition of KPIs

A Key Performance Indicator (KPI) is a quantifiable measure used to assess performance and evaluate the success of a process or system [1]. Originating from business management, they are widely applied to evaluate outcomes and support decision-making. In the context of agro communities, KPIs can integrate agricultural production, economic, environmental, and social science knowledge into decision-making processes, acting as an early warning mechanism to prevent setbacks such as crop failures or community resource depletion.

The concept of KPIs is nuanced and is often misinterpreted as equivalent to other metrics. The distinction lies in their alignment with critical goals or specific targets, which yield measurable and actionable outcomes. While all KPIs are metrics, not all metrics qualify as KPIs. A metric may function as a KPI at one level but not at another. This dynamic nature of KPIs underscores the need for their redefinition based on specific agro community objectives and circumstances, such as improving crop yields, reducing energy consumption, or enhancing social acceptability.

The abundance of data in modern agricultural systems can lead to a proliferation of metrics, complicating the selection and utility of KPIs. To address this, experts use methods like the SMART criteria (Specific, Measurable, Attainable, Relevant, and Timely) to streamline evaluations and manage resources effectively [1]. For agro communities, the SMART approach can guide the design of KPIs that monitor interventions such as sustainable farming practices or GHG emissions reduction.

Additionally, identifying precise needs and expected outcomes helps tailor KPIs to specific agricultural projects. The pillar questions are:

> ***Are we doing the right things?***
> ***It is the effectiveness that indicates the degree to which the work product conforms to requirements. Helps to understand if the outcome is the desirable one.***

> ***Are we doing things right?***
> *It is the efficiency that indicates the degree to which the process produces the required output at minimum resource cost.*

For instance, questions like "What key outcomes do we seek from increased social acceptance?" or "How will reduced energy consumption be measured?" optimize the selection process, making KPIs relevant to the unique challenges of agro communities.

An alternative approach for defining KPIs is based on the CIVITAS framework [2], which outlines the following characteristics for effective indicators:

- Relevance: each indicator should represent an assessment criterion, i.e. have a significant importance for the evaluation process
- Completeness: the set of indicators should consider all aspects of the system/concept under evaluation
- Availability: readily available for entry into the monitoring system
- Measurability: the identified indicators should be capable of being measured objectively or subjectively
- Reliability: clarity of definition and ease of aggregation
- Familiarity: the indicators should be easy to understand
- Non-redundancy: indicators should not measure the same aspect of an assessment criterion
- Independence: small changes in the measurements of an indicator should not affect preferences assigned to other indicators of the evaluation model.

Generally, the indicators in an agro communities context are divided into five types (Figure 1) according to Artley and Stroh (2001) [1]:

Input Indicators	Understand the human and capital resources used to produce the outputs and outcomes.
Process Indicators	Understand the intermediate steps in producing a product or service. In the area of training for example, a process measure could be the number of training courses completed as scheduled.
Output Indicators	Measure the product or service provided by the system or organization and delivered to customers. An example of a training output would be the number of people trained.
Outcome Indicators	Evaluate the expected, desired, or actual result to which the outputs of the activities of a service or organization have an intended effect. For example, the outcome of safety training might be improved safety performance as reflected in a reduced number of injuries and illnesses in the workforce. Establishing a direct cause and effect relationship between the output of the activity and its intended outcome, can be difficult.
Impact Indicators	Measure the direct or indirect effects or consequences resulting from achieving program goals. An example of an impact is the comparison of actual program outcomes with estimates of the outcomes that would have occurred in the absence of the program.

Figure 1. Five types of indicators according to Artley and Stroh (2001) [1]

In agro communities, KPIs can be categorized across different levels of aggregation, such as farm-level, regional, or national. Specific examples include:

- Farm-Level: Yield per hectare, water use efficiency, or soil organic matter.
- Regional-Level: Biodiversity indexes, market participation rates, or food security metrics.
- Community-Level: Indicators like income equality, participation in cooperative systems, or education rates.

Focusing on the "key" aspect of KPIs ensures that these measures are instrumental in assessing current conditions and defining target performance levels, whether it involves sustainable resource use, improving livelihoods, or achieving long-term resilience in agro communities.

3.2 KPI considerations for Agro Communities

Incorporating RES into agro community operations is no longer optional but a necessity. By integrating RES such as solar panels, wind turbines, and biomass energy systems, agro communities can significantly reduce their dependence on fossil fuels, enhance energy efficiency, and decrease carbon emissions. Moreover, these technologies offer additional benefits, such as reduced energy costs, improved energy security, and the opportunity to generate new revenue streams through the sale of excess power back to the grid.

The European Commission has been a driving force in promoting the integration of RES within agricultural and rural contexts. Through initiatives such as the European Green Deal and the "Fit for 55" package, the Commission aims to reduce GHG emissions from Europe by at least 55% by 2030 and achieve carbon neutrality by 2050. Specific funding programs, such as the Common Agricultural Policy (CAP) and the Horizon Europe research framework, provide financial and technical support for agro communities to adopt greener practices and invest in RES. These initiatives emphasize the dual goals of environmental sustainability and rural development, helping to ensure that agro communities remain economically viable while reducing their ecological footprint [3].

To enable agro communities to effectively transition to greener practices, there is a need for a comprehensive blueprint that incorporates RES, addresses their unique challenges, and aligns with sustainability goals. Such a methodology must focus on performance measurement through the use of KPIs tailored to the needs of agro communities. These KPIs should span across multiple dimensions in order to evaluate progress and adoption in a holistic manner:

- Energy Perspective, covering measurements related to energy efficiency, integration of renewable energy systems, annual reductions in GHG emissions, and energy savings achieved through efficiency upgrades.
- Economic Perspective, with KPIs which should reflect energy cost reductions, revenue from renewable energy market transactions, viability of new business models, return on equity, etc.
- Social Perspective, to measure the support of local populations. Indicators in this category should include measures of citizen engagement, user acceptance of new technologies, perceived comfort and air quality improvements, and job creation in green energy sectors.
- Agricultural Perspective, with KPIs to measure the impact of energy transformations on agricultural productivity, resource use efficiency (e.g., water and fertilizers), and resilience to climate-related risks.
- Environmental Perspective, reflecting environmental sustainability, covering biodiversity conservation, reductions in environmental degradation, and overall ecosystem health.

3.3 Review of known initiatives with KPIs for Agro Communities

3.3.1 *ClieNFarms & ClimateFarm Demo Projects*

The ClieNFarms project, funded under Horizon Europe, aims to co-develop and scale up systemic and locally relevant solutions to achieve climate-neutral and climate-resilient farming across Europe. ClieNFarms project runs from 2022 to 2026, making it very relevant to HarvREStt, as these projects run in parallel. ClieNFarms boasts alignment with the European Green Deal and Farm to Fork strategies. Its primary objectives include reducing GHG emissions from farms by at least 50% by 2050, enhancing carbon sequestration, and considering bio geophysical effects such as albedo changes. The project integrates innovative practices in crop and livestock farming, coupled with policy and financial incentives, to enable a sustainable transition while maintaining food security and product quality [4], [5].

ClieNFarms offers farm-level solutions aimed at reducing the climate impact of agricultural production systems in Europe by promoting innovative practices tailored to diverse farming systems (Figure 2). It focuses on systemic approaches that address GHGs, enhance carbon sequestration, and improve overall climate resilience. The project operates across different agricultural systems, including crops, dairy, livestock, and special crop productions, ensuring relevance to various regional and ecological contexts.

Figure 2. ClieNFarms catalogue of climate solutions

ClieNFarms evaluates its solutions through 20 demonstration case studies (Innovative Systemic Solutions Spaces, or I3S) spanning diverse farming systems and geographies, including crops, dairy, and livestock farming across Europe and one case in New Zealand. These solutions undergo testing using advanced modelling tools and multi-criteria assessments, covering environmental impacts, economic viability, and socio-cultural acceptance. KPIs include reductions in GHG emissions, carbon sequestration levels, biodiversity impacts, and water footprint metrics. Monitoring, Reporting, and Verification (MRV) systems leverage remote sensing data and carbon offset platforms to ensure transparency and replication potential. These efforts aim to establish scalable models and foster widespread adoption of sustainable farming practices [6].

The **ClimateFarm Demo** (CFD) project, also funded under Horizon Europe, aims to accelerate the adoption of Climate Smart Farming (CSF) practices across Europe to help achieve the EU's climate neutrality goals. This project began in **2022** and is scheduled to run until **2029**, spanning a total duration of seven years, making it equally relevant to HarvRESt. The extended timeline is designed to allow for the comprehensive testing, demonstration, and scaling of CSF practices across Europe. In its core, CFD fosters a pan-European network of 1,500 Pilot Demo Farmers (PDFs) and Climate Farm Advisors (CFAs) across 28 countries, in order to emphasize knowledge exchange and innovation in agricultural production systems. It promotes solutions for both climate change mitigation (e.g., reducing GHG emissions) and adaptation (e.g., increasing resilience) [7], [8]. Through its activities, CFD also focuses on identifying rewarding mechanisms to incentivize sustainable practices, ensuring their economic feasibility for farmers while supporting long-term climate strategies.

CFD evaluates its impact using various use cases and metrics. The project organizes six annual demo campaigns featuring 4,500 events across diverse pedo-climatic regions, fostering peer-to-peer learning and showcasing practices tailored to different farm types [9]. Ten Living Labs co-create and test innovative CSF practices, while the project measures outcomes through harmonized methodologies. KPIs include reductions in GHG emissions, improvements in carbon sequestration, and adoption rates of sustainable practices among farmers. Additionally, it assesses the scalability and economic viability of CSF solutions through engagement with policymakers and other stakeholders.

3.3.2 *AgroFossilFree Decision Support Tool*

The main objective of the **AgroFossilFree Horizon2020 project** was to create a framework under which all core stakeholders can cooperate to evaluate and promote the currently available fossil-energy-free technologies and strategies (FEFTS) in EU agriculture in a cost efficient manner [10]. AgroFossilFree implemented an online and interactive approach to communication, interaction and knowledge sharing and exchanging through the use of a specifically designed ICT tool, the "AgEnergy Platform" (Figure 3), which deploys the collected information and knowledge on FEFTS in the form of easily accessible end-user material facilitating searching through the use of filters. A Decision Support Tool (DST) based on Fuzzy Cognitive Maps, is integrated seamlessly within the AgroFossilFree platform and allows users to get a ranking of the technologies most suitable for their farm. Essentially, the DST mimics the consultation process of a number of experts if these experts were in the same room evaluating the input data provided by the end-user to propose the most effective action.

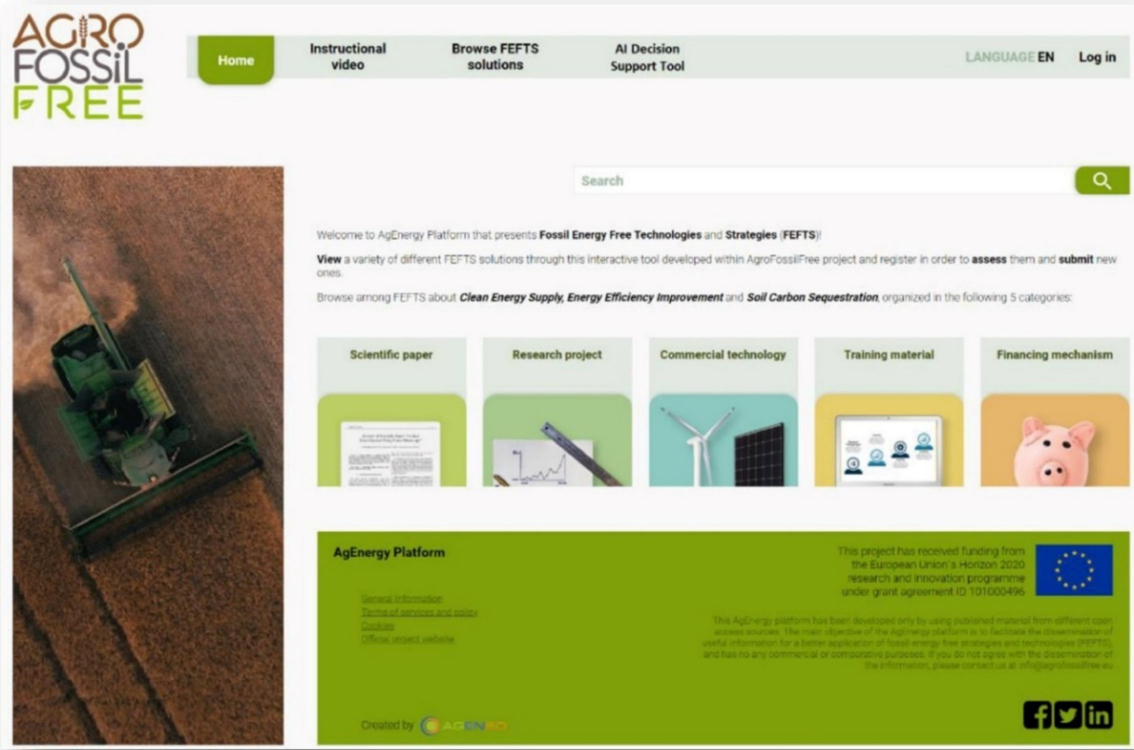

Figure 3. Main AgEnergy Platform webpage

In order to build the “AgEnergy Platform”, domain experts enumerated the parameters that affect the decision to be made, across five contexts: Legal/ regulative/ administrative context (P1), Financial context (P2), Technical context (P3), Social context (P4), Environmental and climate action context (P5). In order to evaluate the parameters, indicators were used. These were identified in literature or decided on a per case basis by the experts. The indicators are used as inputs of the DST.

In order to actually run the DST, user input is also required for calculating the relevant indicators depending on application category. A list of questions was developed with the aim of finding the optimal balance between minimization of questions and collect enough data to provide meaningful results. The outputs are calculated based on the user input and the weights assigned to each indicator.

The approach undertaken in AgroFossilFree Horizon2020 project can be replicated to increase the functionality of other comparable platforms in the Agricultural sector and beyond.

3.3.3 *True Price Assessment Method*

The **True Price Assessment Method (TPAM)** for agri-food products is a framework for revealing the hidden social and environmental costs, or externalities, of producing and consuming agri-food products. These costs, which include GHG emissions, water pollution, and unsafe labour conditions, are not reflected in market prices but significantly affect the planet and society. True pricing assigns a monetary value to these externalities, combining them with the product’s market price to reflect its “true price.” This approach provides transparency, helps identify sustainability gaps, and encourages stakeholders—consumers, producers, and policymakers—to make informed and responsible decisions.

A methodology like TPAM is critical because agri-food value chains are complex, often spanning countries with differing regulations. Many sustainability challenges, such as carbon emissions and labour rights violations, require consistent measurement and management. TPAM fills this gap by quantifying externalities and providing a clear monetary framework to measure their impacts. This allows governments to design more effective policies, helps companies prioritize and compare sustainability interventions, and guides consumers toward making more sustainable choices.

For agri-food producers, the benefits of TPAM are significant. It not only highlights areas for improvement but also enables the communication of positive impacts, such as reductions in emissions or enhanced labour conditions, fostering trust with consumers and investors. The transparency provided by true pricing can also incentivize better practices and innovation, paving the way for long-term sustainability and economic resilience in the agri-food sector. Through structured assessments, TPAM supports alignment with sustainability goals and creates value for all stakeholders in the food system.

In more detail, TPAM identifies and quantifies key environmental and social impacts to calculate the "true price" of agri-food products. As shown in Figure 4, this approach is structured into three components: the valuation framework, assessment methods, and impact-specific modules. These modules provide tailored methodologies for measuring and valuing six environmental (natural) and five social/human capital impacts associated with food production and consumption.

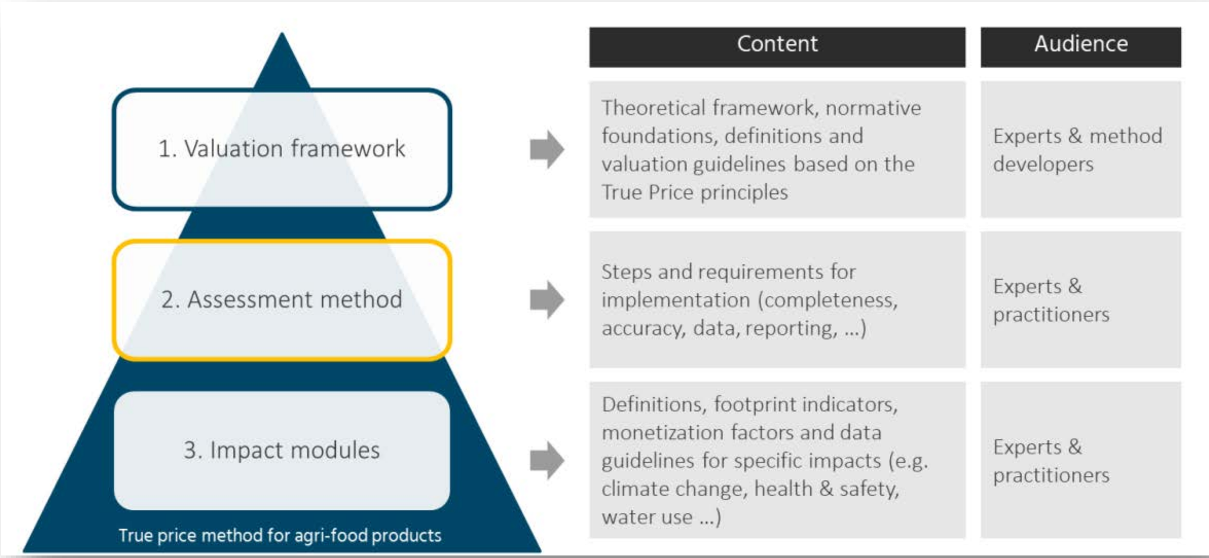

Figure 4. Components of TPAM for agri-food products [11]

The natural impacts addressed include:

- Contribution to climate change (e.g., GHG emissions).
- Land use, biodiversity, and ecosystem service impacts.
- Soil degradation.
- Scarce water use.
- Air, soil, and water pollution.
- Depletion of fossil fuels and other non-renewable materials.

The social and human capital impacts consist of:

- Occupational health and safety.
- Living income for producers.
- Child labour.
- Consumer health.
- Animal welfare.

TPAM offers a standardized methodology for incorporating the above-mentioned into decision-making processes, enabling informed choices by producers, consumers, and policymakers.

3.3.4 *BECoop Project*

The **BECoop project**, funded by European Union's Horizon 2020 programme, aimed at unleashing the untapped potential of community bioenergy by creating favourable conditions and offering technical and business support tools. It aspired to make bioenergy initiatives more attractive to stakeholders while fostering collaboration within the global bioenergy community. As part of Europe's transition to sustainable energy, BECoop promoted bioenergy as a clean, renewable, and locally sourced alternative that reduces carbon emissions and strengthens local economies. The project underscored the multifaceted impact of bioenergy, addressing not only environmental benefits but also societal, economic, and ecological dimensions. By driving tangible actions and partnerships, BECoop exemplified the transformative power of community-driven renewable energy solutions.

Through the establishment of four **Renewable Energy Communities (RESCoops**) in Spain, Poland, Italy, and Greece, BECoop demonstrated the potential of bioenergy to accelerate a fair and inclusive clean-energy transition. These use cases served as testing grounds for innovative practices, focusing on sustainable biomass sourcing and GHG reduction. The project evaluated its impact across multiple dimensions, including self-assessment by RESCoops, socioeconomic advancements, and environmental benefits. A comprehensive analysis revealed critical insights into market uptake, offering lessons and identifying risks to guide future bioenergy community initiatives. This evidence-based approach further underscored BECoop’s contribution to fostering resilient and sustainable local energy systems (Figure 5).

Figure 5. BECoop Poster [12]

A cornerstone of the BECoop project has been its self-assessment tool, designed to evaluate and enhance the viability of community bioenergy projects. The tool featured a methodology and indicators that helped stakeholders assess the current status and potential of their initiatives. By using self-evaluation forms, users could identify the technical, procedural, and business strategies required for success. This roadmap ensured that critical considerations were addressed, providing tailored recommendations and links to relevant resources. Outputs included a visual "spider-net" representation of strengths and weaknesses, a clear status overview, and actionable guidance for developing robust business models. This innovative tool empowered communities to navigate the complexities of bioenergy projects and achieve their goals effectively.

3.3.5 *SPARCS Project*

The **SPARCS project**, funded by the Horizon 2020 program, aimed to transform urban areas into sustainable, positive energy, and zero-carbon communities. It focused on creating citizen-centred, environmentally friendly ecosystems through innovative energy systems and governance models. The project was run by a consortium of 31 entities, including the Lighthouse cities of Espoo (Finland) and Leipzig (Germany), which led large-scale demonstrations. Fellow cities like Maia (Portugal) and Reykjavik (Iceland) worked on replicating these solutions. The project emphasized technologies such as district heating and cooling, renewable energy integration, and active citizen engagement to advance urban energy transformation.

To continuously monitor and evaluate the impact achieved by the implementation of SPARCS interventions in both the Lighthouse and the Fellow cities, an assessment framework was needed. In order to define the SPARCS Holistic Impact Assessment Methodology and the related KPIs, a seven-step approach was introduced as presented in Figure 6 below.

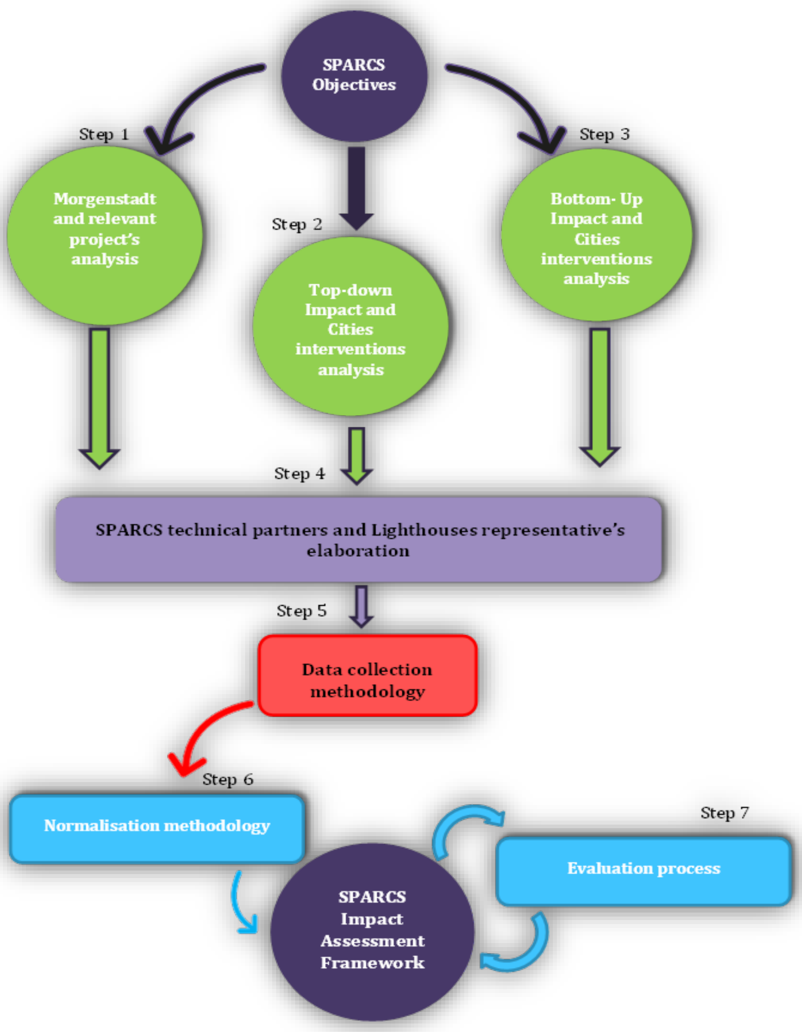

Figure 6. SPARCS seven-step Holistic Impact Assessment Methodology [14]

In Step 1, the detailed analysis of the "Morgenstadt assessment framework" was introduced as well as the evaluation of four Smart City projects related methodologies, as a basis for the subsequent actions, providing guidance and best practices. In Step 2, a top-down approach was adopted to identify the main list of KPIs, drilling into the core of the SPARCS project as a Smart City initiative. In Step 3, a complementing bottom-up method was followed; working with the city stakeholders to co-produce and enhance the list of KPIs, by analysing in detail all planned city interventions and identifying the resulting impacts. Step 4 of the methodology elaborated on the final list of indicators which were used for the needs of the SPARCS project, from the SPARCS technical partners as well as from the city representatives of Leipzig and Espoo; the indicators evaluated the project's technical, socioeconomic, and environmental outcomes, with metrics for energy efficiency, carbon footprint reduction, social inclusion, and economic viability. They were designed to track progress, guide replication, and assess initiatives such as positive energy districts, citizen engagement, and sustainable urban planning. With a complete set of KPIs available, a detailed data requirements analysis to calculate the indicators was performed, followed by a verification of the availability of that data with the city partners, consisting of the Step 5 of the methodology. The normalization methodology in Step 6 dealt with the introduction of a tool for the comparative assessment of the KPIs, towards the objective evaluation of the SPARCS interventions and the easy cross-city adoption. Finally, under Step 7, the SPARCS process evaluation approach and its corresponding activities were introduced, allowing for a complete impact assessment verification, regarding efficiency and effectiveness of the result achieved [14].

The **SPARCS Visualisation Dashboard** (Figure 7) utilises current and historical city data to enable performance monitoring of the project's Lighthouse cities and their respective Positive Energy Districts/Blocks; also enabling tracking of their urban transformation progress towards meeting the city vision.

Figure 7. SPARCS Visualisation Dashboard [13]

The project has yielded significant results, including pioneering business models for positive energy districts, frameworks for replication across Europe, and enhanced mechanisms for citizen participation. By supporting low-carbon transport and renewable energy adoption, SPARCS contributes to achieving carbon neutrality by 2050, highlighting the critical role of communities in sustainable urban development.

3.3.6 *SYNERGY Project*

The **SYNERGY project**, funded under the Horizon 2020 program, focused on addressing the challenges of fragmented and siloed electricity data by enabling collaborative, data-driven innovation across the energy sector. It aimed to transform the energy data landscape through a big data platform that facilitated real-time, secure, and privacy-preserving data sharing among stakeholders. This platform supported holistic optimization of electricity networks and energy performance, fostering synergies across the value chain. SYNERGY's objectives included delivering added-value services for actors like Distribution System Operators, Transmission System Operators, RES operators, and aggregators, introducing innovative business models driven by data analytics, and validating its solutions through large-scale demonstrators.

To assess its outcomes, SYNERGY developed a comprehensive set of KPIs. These indicators evaluated technical aspects like grid stability and energy efficiency, economic factors such as cost-effectiveness and revenue generation, and environmental benefits, including carbon emission reductions. Social metrics assessed user engagement and stakeholder collaboration, ensuring the solutions address diverse needs [15]. The SYNERGY Evaluation Framework was mainly based on the European Electricity Grids Initiative (EEGI) framework, which proposes to compare the benefits of applying Research and Innovation (R&I solutions) with the expected benefits of applying Business as Usual (BaU) solutions (Figure 8).

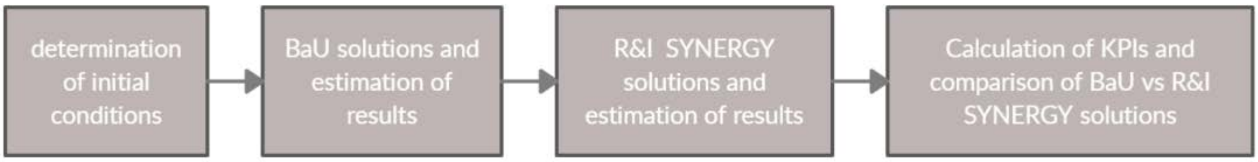

Figure 8. European Electricity Grids Initiative (EEGI) framework Evaluation Proposal [15]

However, considering the data orientation of the SYNERGY project and the functional capabilities of the SYNERGY Big Data Platform, it was also deemed important to evaluate the technical data-related aspects. Therefore, apart from SYNERGY KPIs, a list of Technical KPIs was also defined, introducing a set of Quantitative Technical Evaluation KPIs, Data Asset Quality Evaluation KPIs and User Experience/Acceptance Evaluation KPIs. Another significant component of the SYNERGY Evaluation Framework was the consolidation of validation scenarios per demo case; each validation scenario involving a distinct set of use cases, a distinct set of energy applications relevant to the demo cases, as well as a descriptive narrative of the workflow, data exchange, triggering events, interactions between stakeholders as they interweave within each demo case.

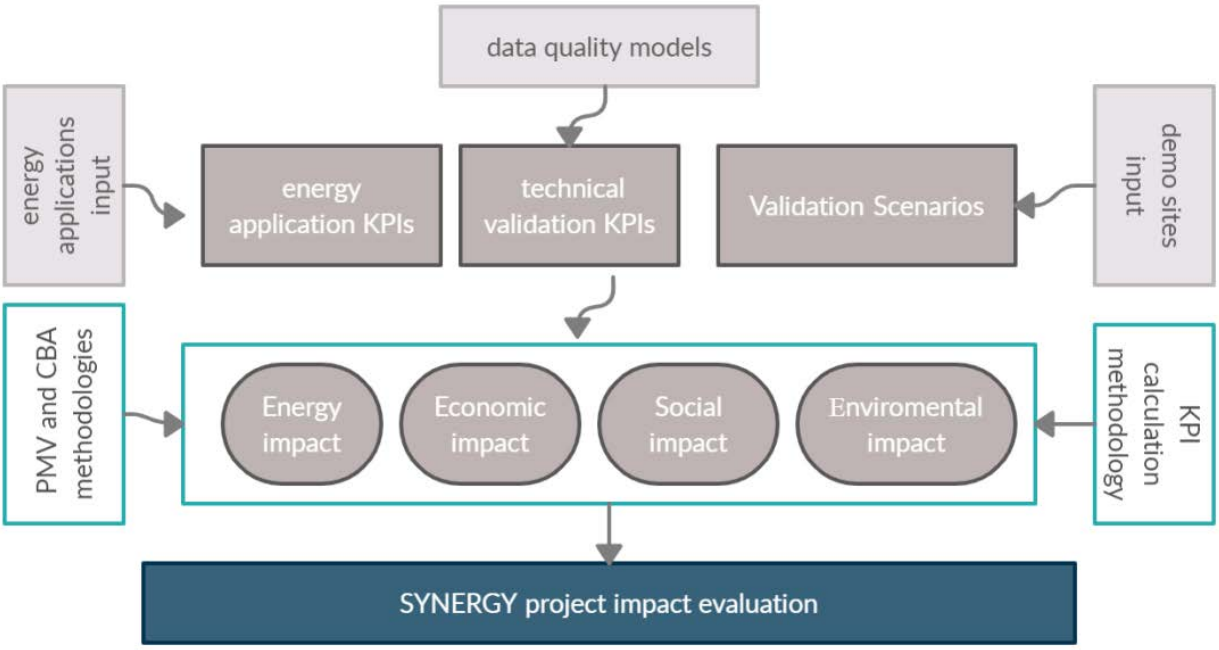

Figure 9. SYNERGY Project Evaluation Framework [15]

The project's impact has been evident in its large-scale demonstrators, which tested the platform across diverse energy scenarios. These demonstrations showcased improved energy system efficiency, enhanced decision-making through real-time analytics, and the integration of RES. The SYNERGY platform has also promoted collaboration between stakeholders, driving the creation of new energy-as-a-service (EaaS) applications. Outcomes included increased grid flexibility, reduced operational costs, and a measurable reduction in carbon footprints across pilot sites. The solid Evaluation Framework facilitated the replication of SYNERGY's innovations across different contexts, supporting the EU's broader sustainability goals.

4. HarvRESt USE CASES KEY PERFORMANCE INDICATORS

4.1 Use Cases outcomes considerations

The **Italian Use Case centres** on **Fattoria Solidale del Circeo**, an organic farm in the Circeo region dedicated to social inclusion and sustainable agriculture. The farm integrates individuals with disabilities into its workforce, fostering personal and professional growth. Located in a Mediterranean climate near the Tyrrhenian Sea, the farm benefits from diverse soil types and water resources, supporting the cultivation of crops like olives, tomatoes, zucchinis, and watermelons. It employs organic farming practices, automated equipment, and advanced irrigation techniques. The farm is also expanding its renewable energy infrastructure with an agro-PV plant and aims to enhance its digital and monitoring systems for improved operations.

As discussed in deliverable D2.1 [16], the expected outcomes of this Use Case encompass the following aspects which should be considered. These include metrics related to the performance of assets, economic impact improvements in agricultural production, enhanced social impact, and increased sustainability of farming practices. These outcomes align with efforts to create new business models that value reduced carbon footprints and social impacts, leveraging renewable energy and exploring opportunities such as carbon credits and ESG-compliant certifications.

The **Danish Use Case** explores opportunities within Denmark's highly advanced agricultural sector, characterized by extensive livestock farming, advanced agronomic practices, and a robust biogas industry. With 62% of its land dedicated to agriculture, the country emphasizes sustainability, leveraging resources like sandy loam and clay soils for diverse crop cultivation and efficient irrigation supported by groundwater. Danish farms integrate precision farming technologies, promote renewable energy use such as wind and biogas, and implement sustainable manure management to enhance productivity and environmental conservation. The Use Case focuses on leveraging these strengths to optimize manure-based biogas production and improve energy self-sufficiency.

As discussed in deliverable D2.1 [16], the expected outcomes of this Use Case encompass the following aspects which should be considered. These include metrics related to the performance of biogas assets, optimization of biogas production processes, and improvements in the economic and environmental impacts of agricultural practices. Specific metrics also address reductions in GHG emissions, advancements in nutrient recovery and management, and scalability potential for innovative business models. This framework supports the development of a biogas planning tool and policy recommendations, aligning with Denmark's sustainability goals and promoting replicable strategies across the EU.

The **first Spanish Use Cas**e focuses on two distinct locations: **Viñas del Vero in Somontano**, Huesca, and **Viñedos del Río Tajo in Guadamur**, Toledo. These sites represent complementary approaches to integrating agricultural practices and renewable energy. Viñas del Vero operates within the Somontano DO, cultivating 15 grape varieties across 515 hectares of vineyards and utilizing advanced energy management systems to optimize winery operations. The area benefits from stony, limestone-rich soils and a Mediterranean climate with continental influences. Conversely, Viñedos del Río Tajo specializes in mechanized grape cultivation for high-quality brandy production on 430 hectares. This region leverages agrivoltaic systems to monitor the effects of partial shading on vine health and grape quality, supported by IoT technologies and precise agricultural methods like vigour mapping and automated irrigation.

As discussed in deliverable D2.1 [16], the expected outcomes of this Use Case encompass the following aspects which should be considered. At VdV, the focus is on energy efficiency and renewable energy integration, with metrics such as solar generation performance, self-consumption ratios, battery storage efficiency, and reductions in grid energy dependence and GHG emissions. Additionally, the operational efficiency of the electric tractor is a key metric. At VRT, metrics include crop yield and quality, such as grape size, sugar content, and leaf area index, alongside vine physiology indicators like trunk diameter variation and photosynthesis rates. Furthermore, the influence of agrivoltaic systems on the microclimate and irrigation water consumption is also monitored to optimize sustainable vineyard management.

The **second Spanish Use Case** is centred on **Torre Santamaria**, a dairy farm and biogas plant in the Noguera region of Catalonia, operated by ACSA-Sorigué. This region, characterized by its continental Mediterranean climate, supports extensive agriculture and livestock farming, including over 25,000 cows. Torre Santamaria has pioneered waste-to-energy practices, processing 30,000 tons of livestock waste and 20,000 tons of agri-food waste annually to produce biomethane, injected directly into the natural gas grid. The surrounding farmland cultivates essential feed crops like alfalfa, corn, and straw, irrigated by the Canal d'Urgell. The site's energy demand, exceeding 5.6 GWh annually, is monitored and optimized through a SCADA system, with both automated and manual data collection processes enhancing energy and nutrient management.

As discussed in deliverable D2.1 [16], the expected outcomes of this Use Case encompass the following aspects which should be considered. These include the optimization of biogas production from agro-residues and the enhancement of nutrient recovery processes from digestate, contributing to improved soil quality and farm circularity. Key metrics to monitor include biogas production efficiency, nutrient recovery rates, and improvements in soil health parameters such as water retention and fertility. Additionally, the assessment of methane production from recycled CO_2 sources offers theoretical insights into advancing renewable energy pathways. These metrics align closely with critical exploitable results, such as biogas planning tools and soil quality methodologies, ensuring sustainability and operational efficiency.

The **Norwegian Use Case** focuses on **Røysland Gaard**, a farm in southwestern Norway managed by Grønn Gardsenergi. The farm spans 2.2 million square meters, featuring grasslands, forests, and two lakes that offer hydropower potential. Dedicated to livestock production, it supports 20 Wagyu cattle and 175 pigs, producing premium meat for high-end establishments. Renewable energy initiatives include PV panels, battery storage, and plans for hydropower installations. The energy demand of 400,000 kWh/year primarily serves the integrated butchery and farm operations. Advanced energy management and monitoring systems aim to achieve energy independence, leveraging local resources and automation to optimize energy use.

As discussed in deliverable D2.1 [16], the expected outcomes of this Use Case encompass the following aspects which should be considered. These include optimizing energy production and reducing costs through the integration of renewable sources, such as PV and hydropower, and leveraging advanced energy management tools. Additionally, metrics focus on reducing environmental impacts and improving sustainability in agricultural practices, aligning with broader goals of economic and environmental benefits. Key exploitable results include smart energy system algorithms, decision support systems (DSS), and innovative business models, supporting scalability and policy recommendations for sustainable energy and agricultural practices across Norway.

4.2 Initial definition of HarvRESt KPIs

In the following sections 4.2.1 through to 4.2.5. a total of **53 preliminary HarvRESt KPIs** have been identified (Figure 10). The HarvRESt KPIs are cover five categories related to agro communities, which have been already identified in section 3.2 above. The following pie chart shows the number of KPIs per category.

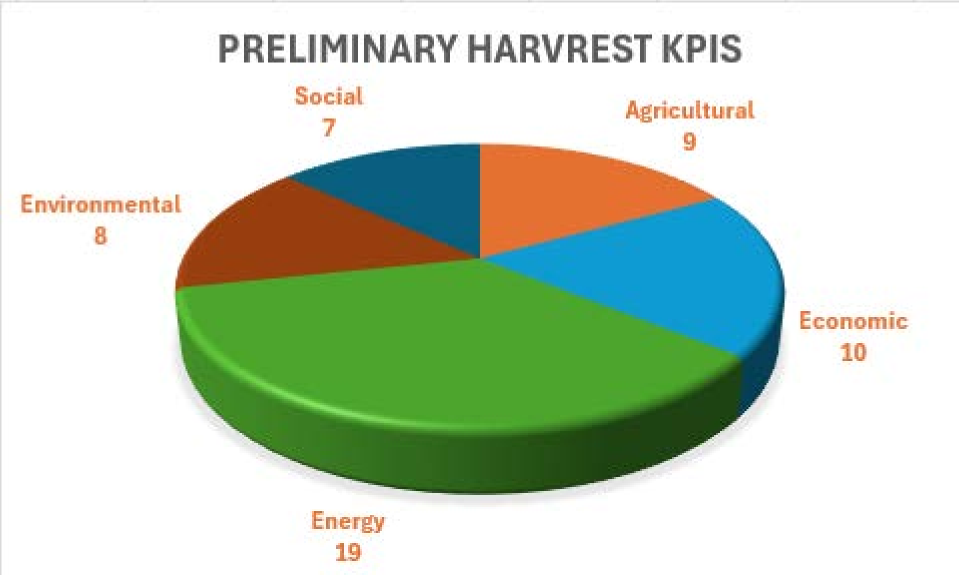

Figure 10. Preliminary HarvRESt KPIs

4.2.1 *Agricultural*

KPI Name	KPI.AG.01 Crop Yield per Hectare and per Plant
Description	Measures the crop production per plant or tree and per hectare of land
Data	Crop Yield: number of fruits /ha, average weight of fruit, fruit production (kg) /ha Total size of land in hectare Total number of plants or trees per hectare
Calculation	Crop yield based on the total production (number of fruits and weight production (kg) obtained per hectare of land
Units	[kg/ha], [kg/plant], [nb fruits/ha], [nb fruits/plant]
Category	Agricultural

KPI Name	KPI.AG.02 Nutrient Use Efficiency
Description	Measures the nutrient recycling from waste in farms and its use as fertilizer in crops
Data	Recycled Nutrient amount Total Nutrient amount Contents of N, P and K in crop biomass NPK dosage applied by the fertilization
Calculation	Recycled Nutrient amount based on nutrient uptake by the crop (i.e. N, P and K contents in plant biomass) / Total Nutrient amount applied by the fertilization
Units	[%]
Category	Agricultural

KPI Name	KPI.AG.03 Soil C and Nutrient Status
Description	Measures the organic and total C contents in the soil, along with the main nutritional parameters (N, P, K)
Data	Soil organic C (SOC), total C Available N (NH_4^+, NO_3^-), total N Available P (PO_4), total P, total K
Calculation	Content of each element (C, N, P, K) per kg of dry soil or per hectare of crop surface
Units	[%], [mg/kg], [kg/ha]
Category	Agricultural

KPI Name	KPI.AG.04 Soil Acidity
Description	Measures the soil pH to detect changes in its acidity
Data	Soil pH
Calculation	Direct measurement in the laboratory/field
Units	-
Category	Agricultural

KPI Name	KPI.AG.05 Grape Quality
Description	Grape quality is a key metric in evaluating agrivoltaic systems, as it reflects the impact of the modified microclimate created by solar panels on agricultural production. This KPI measures critical chemical and organoleptic properties of grapes, such as total acidity, pH, and sugar content (expressed in ºBrix), which are essential for winemaking and consumption
Data	Total acidity pH Sugar content
Calculation	Total Acidity, pH, and Sugar Content are measured in the laboratory using standard analytical methods.
Units	[g/L], [unitless], [degrees Brix]
Category	Agricultural

KPI Name	KPI.AG.06 Leaf Area Index and SA
Description	Measures the vegetation growth and canopy structure
Data	LAI (Leaf Area Index): The ratio of total leaf area to the ground area covered by the plant. It measures the photosynthetic capacity and vegetative growth. SA (Surface Area): The total surface area of vegetation, including leaves, branches, and fruits, exposed to the environment.
Calculation	LAI: leaf area / ground area, m^2 / m^2 SA: ground area, m^2
Units	[LAI: ratio; SA: m^2]
Category	Agricultural

KPI Name	KPI.AG.07 Irrigation Water Consumption
Description	Measures the water consumption by shadowed vines compared to not shadowed vines
Data	Water consumption by shadowed vines per hectare Water consumption by not shadowed vines per hectare
Calculation	Water consumption by shadowed vines per hectare / Water consumption by not shadowed vines per hectare
Units	[Ratio]
Category	Agricultural

KPI Name	KPI.AG.08 Ravaz Index
Description	Measures the vine balance, the relation between vegetative and reproductive production
Data	Crop yield (kg/vine, kg/ha) in the current season (KPI.AG.01) Pruning weight (kg/vine, kg/ha) in the following dormant season
Calculation	Crop yield / Pruning weight
Units	[Ratio]
Category	Agricultural

KPI Name	KPI.AG.09 Trunk diameter variation
Description	Measures the variation in the trunk diameter of vines over a specific period. This KPI compares the growth patterns of vines in shaded areas (under photovoltaic panels) and unshaded areas, providing insights into the impact vine physiology.
Data	Trunk diameter measurements (initial and final) in shaded and unshaded areas, measured using dendrometry. Time period of measurement (e.g., daily, weekly, or seasonal intervals).
Calculation	Trunk Diameter Variation=Final Trunk Diameter−Initial Trunk Diameter
Units	[mm]
Category	Agricultural

4.2.2 *Economic*

KPI Name	KPI.EC.01 Profit per Hectare
Description	Net revenue generated per hectare after accounting for expenses
Data	Net revenue (total revenue minus expenses) Total size of land in hectare
Calculation	Net revenue / Total size of land in hectare
Units	[€]
Category	Economic

KPI Name	KPI.EC.02 Crop Input Cost Ratio
Description	Ratio of total input costs (seeds, fertilizers, pesticides) to total revenue from crops
Data	Total input costs (seeds, fertilizers, pesticides) Total revenue
Calculation	Total input costs / Total revenue
Units	[%]
Category	Economic

KPI Name	KPI.EC.03 Energy Market Revenue
Description	Measures the percentage of total revenues from energy market transactions for the farm
Data	Revenue from energy market transactions Total revenue
Calculation	Revenue from energy market transactions / Total revenue
Units	[%]
Category	Economic

KPI Name	KPI.EC.04 Levelized Cost of Energy
Description	Measures the average cost per unit of energy produced over the entire lifetime of the system
Data	CAPEX = Capital Expenditures (initial investment costs) OPEX = Operational and Maintenance Costs Energy Produced = Total energy output over the lifetime of the project, typically measured in kWh or MWh
Calculation	$LCOE = \frac{\sum(CAPEX + OPEX)}{\sum(Energy\ Produced)}$
Units	[€/kWh] or [€/MWh]
Category	Economic

KPI Name	KPI.EC.05 Net Present Value
Description	Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. It is used to assess the profitability of an investment by discounting future cash flows to their present value
Data	Present value of cash inflows Present value of cash outflows
Calculation	NPV = present value of cash inflows - present value of cash outflows
Units	[€]
Category	Economic

KPI Name	KPI.EC.06 Internal Return Rate
Description	It is the discount rate r that satisfies the net present value (NPV) of cash flows equal to zero. It represents the project's profitability. If the IRR > required rate of return the project is considered profitable.
Data	Cash inflows (e.g., revenues, benefits) for each period. Cash outflows (e.g., costs, investments) for each period. Time periods (t) of cash flows.

Calculation	IRR is the value of r that satisfies: $$0 = \sum_{t=1}^{n} \frac{Cash\ Flow_t}{1 + r^t} - Initial\ Investment$$
Units	[%]
Category	Economic

KPI Name	KPI.EC.08 Energy Purchase Expenditure
Description	Measures the total expense for energy purchases at the Point of Interconnection of the farm
Data	Total expense for energy purchases
Calculation	Total expense for energy purchases
Units	[€]
Category	Economic

KPI Name	KPI.EC.09 OPEX Reduction
Description	Measures the percentage difference in the Operational Expenses of the farm
Data	Total operational expenses initial Total operation expenses final
Calculation	(Operational expenses final – Operational expenses initial) / Operational expenses initial
Units	[%]
Category	Economic

KPI Name	KPI.EC.10 Investment ROI
Description	Measures the return on investment for the farm
Data	Net revenue (total revenue minus expenses) per year Total investment cost
Calculation	Net revenue per year / Total investment cost
Units	[%]
Category	Economic

KPI Name	KPI.EC.11 Levelized Cost of Storage (LCOS)
Description	Measures the average cost per unit of energy stored and delivered over the entire lifetime of the system
Data	CAPEX = Capital Expenditures (initial investment costs) OPEX = Operational and Maintenance Costs FUEL = Price of electricity input Energy Throughput = Total energy stored and delivered over the lifetime of the project, typically measured in kWh or MWh
Calculation	LCOS = ∑Total Costs (CAPEX+OPEX+FUEL) / ∑Energy Throughput
Units	[€/MWh]
Category	Economic

4.2.3 *Energy*

KPI Name	KPI.EN.01 Self-consumption Ratio
Description	Measures the percentage difference in energy self-consumption ratio during a specific timeframe Self-consumption ratio refers to energy that is produced within the farm itself divided by the total amount of energy used by the farm
Data	Energy self-consumption ratio initial Energy self-consumption ratio final
Calculation	(Self-consumption final – Self-consumption initial) / Self-consumption initial

Units	[%]
Category	Energy

KPI Name	KPI.EN.03 Operational Flexibility
Description	Measures the percentage difference of the flexibility capacity of demand assets during a specific timeframe
Data	Flexibility Capacity initial Flexibility Capacity final
Calculation	(Flexibility Capacity final – Flexibility Capacity initial) / Flexibility Capacity initial
Units	[%]
Category	Energy

KPI Name	KPI.EN.04 Energy Storage Capacity
Description	Measures the percentage difference of the energy storage capacity during a specific timeframe
Data	Energy Storage Capacity initial Energy Storage Capacity final
Calculation	(Energy Storage Capacity final – Energy Storage Capacity initial) / Energy Storage Capacity initial
Units	[%]
Category	Energy

KPI Name	KPI.EN.05 Energy Export Ratio
Description	Measures the percentage difference in energy export share during a specific timeframe Energy export share refers to energy that is sold to the grid divided by the total amount of energy produced within the farm
Data	Energy Export Share initial Energy Export Share final
Calculation	(Energy Export Share final – Energy Export Share initial) / Energy Export Share initial
Units	[%]
Category	Energy

KPI Name	KPI.EN.06 Energy Import Ratio
Description	Measures the percentage difference in energy import share during a specific timeframe Energy import share refers to energy that is bought from the grid divided by the total amount of energy consumed by the farm
Data	Energy Import Share initial Energy Import Share final
Calculation	(Energy Import Share final – Energy Import Share initial) / Energy Import Share initial
Units	[%]
Category	Energy

KPI Name	KPI.EN.07 Effective Renewable Generation
Description	Measures the amount of renewable energy that was produced within the farm
Data	Renewable Energy Produced
Calculation	Renewable Energy Produced
Units	[MWh]
Category	Energy

KPI Name	KPI.EN.08 Renewable Energy Surplus
Description	Measures the amount of renewable energy that was produced within the farm which was not used by the farm
Data	Renewable Energy Produced Renewable Energy Consumed
Calculation	Renewable Energy Produced – Renewable Energy Consumed
Units	[MWh]
Category	Energy

KPI Name	KPI.EN.09 Effective Consumption
Description	Measures the amount of energy consumed within the farm during a specific period
Data	Energy consumed
Calculation	Energy consumed
Units	[MWh]
Category	Energy

KPI Name	KPI.EN.10 BESS Cycles (net capacity)
Description	Equivalent cycles of BESS based on the effective battery capacity (max charge-min charge)
Data	Energy Throughput = Total energy stored and delivered over the lifetime of the project, typically measured in kWh or MWh Effective BESS Capacity = Real capacity considering the max charge-min charge BESS boundaries
Calculation	BESS net Cycles = ∑Total Energy Throughput / Effective BESS Capacity
Units	[Cycles]
Category	Energy

KPI Name	KPI.EN.11 BESS Cycles (total capacity)
Description	Equivalent cycles of BESS based on the total (nominal) battery capacity
Data	Energy Throughput = Total energy stored and delivered over the lifetime of the project, typically measured in kWh or MWh Nominal BESS Capacity = Total capacity not considering max charge-min charge BESS boundaries
Calculation	BESS total Cycles = ∑Total Energy Throughput / Nominal BESS Capacity
Units	[Cycles]
Category	Energy

KPI Name	KPI.EN.12 Electric Tractor Operational Efficiency
Description	Measures the energy consumption per hour of electric tractor operation
Data	Energy Consumed: The total energy consumed during charging (e.g., in MWh or kWh) Operating Hours: The total hours the tractor has been operated
Calculation	$Operational\ Efficiency = \frac{Energy\ Consumed}{Operating\ hours}$
Units	[MWh/hour] or [kWh/hour]
Category	Energy

KPI Name	KPI.EN.13 Energy Use Intensity
Description	Measures the amount of energy used per unit of production output (e.g., per kilogram of crop produced, per unit of livestock, or per hectare of land)
Data	Total Energy Consumed Unit of Production
Calculation	Energy Consumed
Units	[MWh/unit of production output]
Category	Energy

KPI Name	KPI.EN.14 PV Performance in an Agrivoltaic System
Description	Measures the efficiency of a solar Agri PV system. It represents the ratio of actual energy generated in a one axe tracker installation tracking the sun with a modified algorithm that benefits the crop to the theoretical energy expected in the same installation using the standard astronomical sun tracking algorithm
Data	PV Energy Produced with a modified algorithm that benefits the crop PV Potential Energy Expected with the standard astronomical algorithm
Calculation	PV Energy Produced with a crop under panels (modified sun tracking algorithm) / PV Energy produced without crop (standard astronomical sun tracking algorithm)
Units	[%]
Category	Energy

KPI Name	KPI.EN.15 Renewable Energy Share
Description	Measures the percentage of renewable energy that is used by the farm divided by the total amount of energy used by the farm
Data	Renewable Energy Consumed Total Energy Consumed
Calculation	Renewable Energy Consumed / Total Energy Consumed
Units	[%]
Category	Energy

KPI Name	KPI.EN.16 Energy Consumption Reduction
Description	Measures the percentage in total energy consumption during a specific timeframe
Data	Total Energy Consumed initial Total Energy Consumed final
Calculation	(Total Energy Consumed final – Total Energy Consumed initial) / Total Energy Consumed initial
Units	[%]
Category	Energy

KPI Name	KPI.EN.17 Energy Recovery Ratio
Description	Measures the percentage of energy that is recovered and reused within the farm system
Data	Recycled Energy Total Energy Consumed
Calculation	Recycled Energy / Total Energy Consumed
Units	[%]
Category	Energy

KPI Name	KPI.EN.18 PV Performance Ratio
Description	Measures the overall efficiency of a solar photovoltaic system. It represents the ratio of actual energy generated to the theoretical energy expected under ideal conditions
Data	PV Energy Produced PV Energy Expected
Calculation	PV Energy Produced / PV Energy Expected
Units	[%]
Category	Energy

KPI Name	KPI.EN.19 Effective energy charged in BESS
Description	Measures the total amount of energy charged into the BESS during a specific period
Data	Energy input to BESS (measured in MWh)
Calculation	Sum of all energy charged into the BESS over the evaluation period.
Units	[MWh]
Category	Energy

KPI Name	KPI.EN.20 Effective energy discharged from BESS
Description	Measures the total amount of energy discharged from the BESS during a specific period.
Data	Energy output from BESS (measured in MWh).
Calculation	Sum of all energy discharged from the BESS over the evaluation period.
Units	[MWh]
Category	Energy

4.2.4 *Environmental*

KPI Name	KPI.EV.01 Soil Quality Impact
Description	Measures the RES impact on soil quality / soil degradation based on soil organic carbon loss texture, fertility, acidity and microbial activity.
Data	Soil organic C (SOC), organic matter Soil texture (% of clay, sand and silts) Soil fertility (N, P, K content) Soil pH Soil biological activity
Calculation	Determination of soil organic C, nutrient content (N, P, K), texture, pH and microbial activity
Units	[%], [μg/g], [mg/kg], [kg/ha]
Category	Environmental

KPI Name	KPI.EV.02 Reduction in GHG Emissions
Description	Measures the percentage difference in GHG emissions during a specific timeframe
Data	GHG Emissions initial GHG Emissions final
Calculation	(GHG final – GHG initial) / GHG initial
Units	[%]
Category	Environmental

KPI Name	KPI.EV.03 Reduction in CO_2 Emissions
Description	Measures the percentage difference in CO_2 emissions during a specific timeframe
Data	CO_2 Emissions initial CO_2 Emissions final
Calculation	(CO_2 final – CO_2 initial) / CO_2 initial
Units	[%]
Category	Environmental

KPI Name	KPI.EV.04 N & P Losses
Description	Measures the soil losses in Nitrate and Phosphorus (including N & P leaching and NH_3 emissions)
Data	Available N (NH_4^+, NO_3^-), total N Available P (PO_4), total P NH_3 emissions
Calculation	Content of N and P at different soil depths to estimate leaching process, and analysis of NH_3 emissions from the soil (when the product is applied).
Units	[%], [mg/kg], [kg/ha]
Category	Environmental

KPI Name	KPI.EV.05 Carbon Emissions Intensity
Description	Measures the amount of carbon emissions released per unit of production output (e.g., per kilogram of crop produced, per unit of livestock, or per hectare of land)
Data	Total CO_2 Emissions Unit of Production
Calculation	CO_2 Emissions
Units	[kTons]
Category	Environmental

KPI Name	KPI.EV.06 Changes in the crop micro-climate (ETo reduction)
Description	The potential Evapotranspiration (mm) measures the amount of water lost by plants transpiration and soil evaporation and it is a great calculation for expressing all the atmospheric parameters (temperature, RH, wind speed and solar radiation) The coexistence of solar panels with a crop in an Agri PV system may change this parameters, expecting the ETo to be reduced by the partial shadowing of the crop.
Data	ETo (mm) in shaded plants by PV panels ETo (mm) in not shaded plants
Calculation	(ETo in shaded plants by PV panels – ETo in not shaded plants) / ETo in not shaded plants
Units	[%]
Category	Environmental

KPI Name	KPI.EV.07 Reduction of soil and air temperature
Description	In an Agri PV the crop is partially shaded by solar panels. This shadowing may result in the reduction of temperature (both air and soil temperature) in shaded areas. This temperature reduction can be important in the event of a heat wave, making plants have a bigger physiological activity and lower thermal stress.
Data	Air temperature (ºC) and soil temperature (ºC) at different depths in plants shaded by solar panels; continuously measured by T sensors Air temperature (ºC) and soil temperature (ºC) at different depths in not shaded plants; continuously measured by T sensors
Calculation	(Air and Soil Temperature in shaded plants by PV panels – Air and Soil Temperature in not shaded plants) / Air and Soil Temperature in not shaded plants
Units	[%]
Category	Environmental

KPI Name	KPI.EV.08 Reduction of Solar Radiation received by the crop
Description	In an Agri PV the crop is partially shaded by solar panels. It is important to know and measure the solar radiation received by the crop, and it is going to be reduced compared to the same crop never shaded
Data	Solar radiation (W/m^2) received by plants partially shaded by solar panels; continuously measured with a pyranometer

	Solar radiation (W/m^2) received by plants not shaded; continuously measured with a pyranometer
Calculation	(Solar radiation on shaded plants by PV panels – Solar radiation on not shaded plants) / Solar radiation on not shaded plants
Units	[%]
Category	Environmental

4.2.5 *Social*

KPI Name	KPI.SC.01 Social Acceptability
Description	Measures the farmers' social impact
Data	Based on availability of the information, this KPI could be estimated based on: Age, Income, Installation costs, Visibility, Noise, Sex, Household size, Ownership status (owners or tenants), Environmental education level, Proximity to existing energy sources (in km)
Calculation	A weight of importance should be defined for each selected parameter based on bibliography
Units	[Likert scale 1-5]
Category	Social

KPI Name	KPI.SC.02 Adoption Tendency
Description	Measures the likelihood to scale-up the developed solutions
Data	Questionnaire (TBD)
Calculation	Qualitative estimation
Units	[Likert scale 1-5]
Category	Social

KPI Name	KPI.SC.03 Awareness Increase
Description	Measures the increase in stakeholders' awareness around decarbonized farming processes and energy sufficiency
Data	Questionnaire (TBD)
Calculation	Qualitative estimation
Units	[Likert scale 1-5]
Category	Social

KPI Name	KPI.SC.04 Interest Creation
Description	Measures the increase in local stakeholders' interest in smart energy systems
Data	Questionnaire (TBD)
Calculation	Qualitative estimation
Units	[Likert scale 1-5]
Category	Social

KPI Name	KPI.SC.05 RES-enabled Farming Satisfaction
Description	Measures the satisfaction of farm stakeholders from the transition to RES-enabled farming
Data	Questionnaire (TBD)
Calculation	Qualitative estimation
Units	[Likert scale 1-5]
Category	Social

KPI Name	KPI.SC.06 RES-enabled Farming Engagement
Description	Measures the engagement of farm stakeholders/ employees in RES-enabled sustainable farming
Data	Questionnaire (TBD)
Calculation	Qualitative estimation
Units	[Likert scale 1-5]
Category	Social

KPI Name	KPI.SC.07 Public Engagement
Description	Measures how actively the public participates in or supports energy transition initiatives in the agricultural sector
Data	It could be measured by measuring adoption rates of local farms and business implementing renewable energy technologies or practices. Alternatively, could be measured by surveys asking about awareness and willingness to engage in energy transition for example.
Calculation	Qualitative estimation
Units	[Likert scale 1-5]
Category	Social

4.3 Mapping of HarvRESt KPIs

In the following traceability matrix (Table 1), each KPI is assigned to one or more HarvRESt Use Cases. The KPIs marked as **bold** are those which have been adopted by **more than one Use Cases**, therefore considered, at the time of writing this deliverable, as the most possible ones to be used as a basis, further elaborated and used in the duration of the project. **The "common" KPIs are 34 in total**.

Table 1. HarvREStKPIs and use cases traceability matrix

KPI ID	Spanish Use Case (VdV)	Spanish Use Case (VRT)	Spanish Use Case (Torre Santamaria)	Italian Use Case	Norwegian Use Case	Danish Use Case
KPI.AG.01		x	x			
KPI.AG.02			x			x
KPI.AG.03		x	x			
KPI.AG.04			x			
KPI.AG.05		x				
KPI.AG.06		x				
KPI.AG.07		x				
KPI.AG.08		x				
KPI.AG.09		x				
KPI.EC.01		x	x	x		x
KPI.EC.02		x		x		
KPI.EC.03		x	x	x	x	x
KPI.EC.04	x	x	x		x	
KPI.EC.05	x		x	x	x	
KPI.EC.06			x		x	
KPI.EC.08	x	x	x		x	
KPI.EC.09	x				x	
KPI.EC.10	x		x		x	
KPI.EC.11	x	x		x	x	x
KPI.EN.01	x	x			x	x
KPI.EN.03					x	
KPI.EN.04	x					
KPI.EN.05	x	x	x		x	
KPI.EN.06	x	x	x		x	
KPI.EN.07	x	x	x		x	
KPI.EN.08	x	x			x	
KPI.EN.09	x	x	x		x	
KPI.EN.10	x				x	
KPI.EN.11	x				x	
KPI.EN.12	x					

KPI ID	Spanish Use Case (VdV)	Spanish Use Case (VRT)	Spanish Use Case (Torre Santamaria)	Italian Use Case	Norwegian Use Case	Danish Use Case
KPI.EN.13		x	x		x	
KPI.EN.14		x				
KPI.EN.15	x	x			x	
KPI.EN.16					x	
KPI.EN.17					x	
KPI.EN.18	x	x		x	x	
KPI.EN.19		x				
KPI.EN.20		x				
KPI.EV.01		x	x			
KPI.EV.02	x		x	x	x	x
KPI.EV.03	x	x	x	x	x	x
KPI.EV.04			x			
KPI.EV.05		x			x	
KPI.EV.06		x				
KPI.EV.07		x				
KPI.EV.08		x				
KPI.SC.01	x	x	x	x	x	x
KPI.SC.02	x	x	x	x	x	x
KPI.SC.03				x	x	
KPI.SC.04	x				x	
KPI.SC.05			x	x	x	
KPI.SC.06					x	
KPI.SC.07	x	x	x	x	x	x

4.4 Monitoring & assessment approach

Continuing from section 3.1 above, to ensure KPIs are effective, they must be SMART: Specific, Measurable, Achievable, Relevant, and Time-bound. Being Specific means clearly defining what is to be measured and ensuring that there is no ambiguity in the objective. Measurable refers to the ability to track the KPI through quantifiable data, making it easier to determine progress. Achievable indicates that the KPI should be realistic, considering the resources and constraints in its measurement. Furthermore, KPIs should be Relevant to the overarching goals of the project, ensuring they align with its priorities as defined in the DoA. Lastly, Time-bound KPIs are essential because they establish deadlines and timeframes for achievement.

In an effort to align with the above principles, in section 4.2 above, for each KPI a title and a description have been provided, accompanied by the data needed for its calculation, the calculation formula and the measurement unit (Table 2).

Table 2. Parameters analysed in each KPI description

KPI Name	ID and name of the KPI
Description	Description of the KPI and its goal
Data	Data needed in order to calculate this KPI
Calculation	Calculation formula for this KPI
Units	Measurement units for this KPI
Category	Category to which this KPI belongs

Furthermore, in order to be able to obtain results that are detached from the specificities of the project's Use Cases and to baseline, to the extend possible, the KPIs collected from agro communities integrating RES, a comprehensive approach that considers environmental, social, and economic dimensions is essential. In this context, HarvRESt project could consider the following standards, protocols and initiatives, as benchmarks in order to be able to compare the project's results with similar findings of analogous projects. At the moment of writing this deliverable, the following are presented as considerations only.

The Greenhouse Gas Protocol (GHG Protocol) [17] could be a central framework for quantifying farm-level emissions, offering standardized methodologies for calculating direct and indirect emissions associated with energy production and usage. By applying this protocol, we could determine the net carbon footprint of RES integration, assess reductions in GHG emissions, and compare these metrics with traditional energy systems. Additionally, life cycle assessment techniques could be employed to evaluate the broader environmental impact of RES deployment, including resource efficiency and waste management.

From a social perspective, the Social Accountability 8000 standard [18] could provide guidance on assessing and improving labor conditions, community well-being, and social equity within agro communities. This framework emphasizes metrics such as fair wages, safe working conditions, and stakeholder engagement, which are critical for understanding how RES integration impacts social dynamics. By aligning KPIs with SA8000, the project could monitor whether the adoption of renewable technologies creates equitable opportunities or addresses any potential challenges faced by vulnerable populations within the communities.

For economic and productivity metrics, the OECD Indicators for Agriculture [19] offer valuable benchmarks for evaluating the financial and operational performance of farms incorporating RES. These indicators enable a comparative analysis of parameters such as energy cost savings, crop yield improvements, and overall farm profitability. Integrating these benchmarks into the project could ensure that the economic outcomes of RES adoption are not only measurable but also contextualized within broader agricultural trends.

4.5 Data collection & processing

The data collection process shall integrate multiple sources to provide a comprehensive view of agro community dynamics. Questionnaires and/or survey replies shall capture qualitative data, such as farmer perceptions and socio-economic conditions, allowing for the calculation of qualitative KPIs, more prominently in the "Social" category, but also in the "Economic" category. IoT sensors, installed in the farms, or in the systems used by the farms for monitoring reasons, shall provide real-time monitoring of metrics like PV systems energy generation, or energy usage of the electric tractor. Additionally, publicly available datasets, such as those from FAOSTAT [20] and national agricultural databases, could be used to enrich the analysis with historical and comparative data. The Use Cases of the HarvREst project are vital for gathering context-specific information, such as local PV installations and their particularities, energy expenditure and energy availability, ensuring data relevance and granularity.

To ensure comparability, collected datasets shall be normalized, in order to account for variability in agro-ecological conditions, enabling fair comparisons across different regions. Statistical models and machine learning techniques shall be employed to isolate and adjust for these confounding factors, ensuring the data reflects true performance differences rather than external influences. Benchmarking shall also involve aligning the data with international standards, as described in section 4.4 above.

Before feeding them to the analytics pipelines, the collected datasets shall undergo rigorous pre-processing to enhance their quality and usability. Handling missing or incomplete data is critical; techniques like imputation (mean, median, or machine learning-based) and sensitivity analysis shall be used to fill gaps without compromising accuracy. Semantic enrichment shall standardize and contextualize the data, such as unifying units of measurement, annotating data with metadata, and harmonizing terminologies to ensure consistency. These steps should establish clean, enriched datasets ready for analysis. With this foundation, continuous monitoring and real-time KPI assessment become feasible, enabling dynamic decision-making and adaptive management in the context of the HarvREst project's goals.

4.6 KPI conflicts

After the definition of preliminary HarvREst KPIs (section 4.2) and the subsequent assignment of those KPIs to the project's Use Cases (section 4.3), an initial identification of conflicting KPIs was performed.

Initially, the identification of possible conflicts at this point has been at a high-level, purely based on the definition and objective of each KPI, according also to the expertise of those partners who proposed each KPI. As a further step, the degree of conflict was assessed (Low or High). Building upon this preliminary work, further analysis of the conflict extent shall be performed in WP4 and WP6 where the weighting criteria (and respective trade-offs) will be assessed.

The following Table 3 presents the possible conflicts between HarvREst KPIs.

Table 3. Conflicting HarvREStt KPIs

KPI ID	KPI ID	Conflict Level
KPI.AG.01 Crop Yield per Hectare and per Plant	KPI.EC.03 Energy Market Revenue	High
	KPI.EN.01 Self-consumption Ratio	High
	KPI.EN.04 Energy Storage Capacity	High
	KPI.EN.05 Energy Export Ratio	High
	KPI.EN.07 Effective Renewable Generation	High
	KPI.EN.14 PV Performance in an Agrivoltaic System	High
	KPI.EN.18 PV Performance Ratio	High
	KPI.EN.19 Effective energy charged in BESS	High
	KPI.EV.02 Reduction in GHG Emissions	High
	KPI.EV.03 Reduction in CO_2 Emissions	High
KPI.AG.05 Grape Quality	KPI.EC.03 Energy Market Revenue	Low
	KPI.EN.07 Effective Renewable Generation	High
	KPI.EN.14 PV Performance in an Agrivoltaic System	High
	KPI.EN.18 PV Performance Ratio	High
KPI.AG.06 Leaf Area Index and SA	KPI.EC.03 Energy Market Revenue	High
	KPI.EN.07 Effective Renewable Generation	High
	KPI.EN.18 PV Performance Ratio	Low
KPI.AG.07 Irrigation Water Consumption	KPI.EN.07 Effective Renewable Generation	Low
	KPI.EN.14 PV Performance in an Agrivoltaic System	Low
	KPI.EN.18 PV Performance Ratio	Low
KPI.EC.01 Profit per Hectare	KPI.EC.03 Energy Market Revenue	High
	KPI.EC.04 Levelized Cost of Energy	Low
	KPI.EC.09 OPEX Reduction	Low
	KPI.EN.01 Self-consumption Ratio	High
	KPI.EN.04 Energy Storage Capacity	High
	KPI.EN.05 Energy Export Ratio	High
	KPI.EN.19 Effective energy charged in BESS	High
	KPI.EV.02 Reduction in GHG Emissions	High
	KPI.EV.03 Reduction in CO_2 Emissions	High

KPI ID	KPI ID	Conflict Level
KPI.EC.03 Energy Market Revenue	KPI.EN.01 Self-consumption Ratio	High
	KPI.EN.04 Energy Storage Capacity	High
	KPI.EN.06 Energy Import Ratio	Low
	KPI.EN.08 Renewable Energy Surplus	High
	KPI.EN.19 Effective energy charged in BESS	Low
	KPI.EV.06 Changes in the crop micro-climate (ETo reduction)	Low
	KPI.EV.07 Reduction of soil and air temperature	Low
	KPI.EV.08 Reduction of Solar Radiation received by the crop	Low
KPI.EC.06 Internal Return Rate	KPI.EV.03 Reduction in CO_2 Emissions	Low
KPI.EC.08 Energy Purchase Expenditure	KPI.EC.10 Investment ROI	Low
KPI.EC.10 Investment ROI	KPI.EN.06 Energy Import Ratio	Low
KPI.EC.10 Investment ROI	KPI.EN.19 Effective energy charged in BESS	Low
KPI.EN.01 Self-consumption Ratio	KPI.EN.19 Effective energy charged in BESS	Low
	KPI.EV.08 Reduction of Solar Radiation received by the crop	Low
KPI.EN.04 Energy Storage Capacity	KPI.EV.08 Reduction of Solar Radiation received by the crop	Low
KPI.EN.07 Effective Renewable Generation	KPI.EV.06 Changes in the crop micro-climate (ETo reduction)	Low
	KPI.EV.07 Reduction of soil and air temperature	Low
	KPI.EV.08 Reduction of Solar Radiation received by the crop	Low
KPI.EN.14 PV Performance in an Agrivoltaic System	KPI.EV.06 Changes in the crop micro-climate (ETo reduction)	Low
	KPI.EV.07 Reduction of soil and air temperature	Low
	KPI.EV.08 Reduction of Solar Radiation received by the crop	Low
KPI.EN.18 PV Performance Ratio	KPI.EV.06 Changes in the crop micro-climate (ETo reduction)	Low
	KPI.EV.07 Reduction of soil and air temperature	Low
	KPI.EV.08 Reduction of Solar Radiation received by the crop	Low

5. CONCLUSIONS

This deliverable presented the outcomes of the project's efforts to define KPIs and analyse their interaction within the context of RES integration in agro communities. At first, it established a foundational understanding of KPIs and highlighted key considerations specific to agro communities for selecting appropriate indicators. It then conducted desk research of existing projects and initiatives in the same domain, in order to ensure alignment with current advancements and to identify any possible gaps in the measurement of RES integration in agricultural contexts.

Building on this foundation, insights from prior work conducted within HarvRESt, related to Use Case outcomes, was taken on board in order to act as a stepping stone for the proposal of a comprehensive, yet preliminary, set of KPIs across five categories: agricultural, economic, energy, environmental, and social. Each KPI has been carefully defined to ensure practical application and reliability, with detailed measurement guidelines provided. These guidelines include the necessary data inputs, calculation formulas, and units of measurement, ensuring consistency and applicability across different Use Cases.

Additionally, a traceability matrix was developed to map the relevance of each KPI to specific Use Cases, providing clarity for performance assessment both at the granular level of individual Use Cases and across the project as a whole. Additionally, the deliverable took on the challenge of ensuring that KPI results are broadly applicable beyond the specificities of the project's Use Cases. Where feasible, benchmarking considerations were provided to align the proposed KPIs with data from existing agro communities, thereby enabling comparative analysis and enhancing the generalizability of findings.

Moreover, the deliverable discussed the initial considerations on data collection and pre-processing to standardize data gathering and improve the robustness of KPI measurement across the five project's Use Cases. This structured approach lays the groundwork for evaluating the integration of RES in agricultural communities. Future work in upcoming Work Packages will build on this foundation to explore trade-offs, refine weighting criteria, and further analyze the interaction between KPIs. This iterative process aims to support the development of sustainable, scalable frameworks for RES integration in agro communities.

Finally, an assessment of the conflicting KPIs was performed based on the definition of each KPI and the expertise Consortium. Further analysis of the conflict extent shall be performed in WP4 and WP6 where the weighting criteria (and respective trade-offs) will be assessed.

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HarvRESt
Greener 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, HarvRESt seeks 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. HarvRESt will 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.

PARTNER		SHORT NAME
circe Creating together	CIRCE Research Centre	CIRCE
Beta UVIC	BETA Technological Centre	BETA (UVic)
NORCE	NORCE	NORCE
TECNOALIMENTI	Tecnoalimenti	TCA
WHITE	WHITE	WR
Suite5 We Deliver Intelligence	Suite5 Data Intelligence Solutions Ltd.	Suite5
EnGreen	EnGreen	EnG
ConTerra	ConTerra	CT
Confagricoltura	Confagricoltura	CONFAGRI

	Fattoria Solidale del Circeo	FSDC
	Viñas del Vero	VdV
	Viñedos del Rio Tajo	VRT
	Sorigué	ACSA-Sorigué
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