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Symbiosyst

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Executive Summary

This deliverable, part of the work performed within Symbiosyst Task 4.1, focuses on the sustainability and eco-design of agrivoltaics fields. The primary goal of the present study is to establish an innovative methodology based on a set of Key Performance Indicators (KPIs) to measure the sustainability of this kind of systems. This extends the early design analysis performed in WP2 and incorporates the innovative reliability and performance measurement solutions from WP3.

Measuring the sustainability of an agrivoltaic field is a crucial step, because it ensures that the integration of agricultural and photovoltaic systems is beneficial, not only economically but also socially and environmentally. By evaluating sustainability, we can identify, prevent and mitigate potential negative impacts of renewable energy projects on crops, biodiversity, soil health, and communities. This also can help optimizing the efficiency and longevity of both agricultural and solar components, ensuring that agrivoltaic systems can contribute positively to the higher goal of food security and reaching renewable energy targets.

The KPI-based methodology described within this report is specific to agrivoltaic systems in open and closed crop fields, but it has potential for broader application in other type of systems such as farm-integrated agrivoltaics, or for other renewable energy related projects. The KPIs cover various sustainability aspects, including ethical, social, environmental, eco-design, and agricultural dimensions. Economic aspects are addressed in more details in Deliverable 7.3, while the impact on local communities was further analysed in Deliverable 6.2.

A questionnaire was created to evaluate these KPIs, and each KPI was linked to a Sustainable Development Goal (SDG) to ease the visualization of results. The questionnaire is being tested thanks to the support of several agrivoltaics demonstrators, internal and external to the project consortium, and their feedback will be used to further refine the methodology. This validation process involves two rounds of testing: initially with internal agrivoltaics demonstrators and subsequently with external ones. The questionnaire and scoring method will be available in the SYMBIOSYST website for public consultation, and it can be used from agrivoltaics field owners as a self-evaluation about their sustainability. It covers all the sustainability-related aspects that are relevant for the agrivoltaic sectors, like social responsibility, solar energy conversion efficiency, landscape integration of PV components, agricultural quality and biodiversity. The first results of the methodology test will be aggregated and shared publicly in Deliverable 4.4.

The questionnaire, developed with input from experts in various fields, consists of 66 questions divided into four sections as follows:

- Agrivoltaic field information (11 questions)
- Social sustainability (16 questions)
- Photovoltaic system sustainability (20 questions)
- Agricultural system sustainability (20 questions)

The present deliverable begins with an introduction to the activity (Section 1), it follows with the state of the art of sustainability evaluation for agrivoltaics (Section 2), providing a comprehensive overview of current methodologies and practices. In Section 3 the full KPI-based methodology is explained, and the first draft of the questionnaire is available in ANNEX I for public consultation. Section 4 outlines the SDG-based KPIs and associated scoring method, explaining the KPIs and the approach used to evaluate them. A full list of the selected KPIs is available in ANNEX II. Finally, the document concludes with a summary of the activity and description of next steps, offering a recap of the findings and outlining future actions.

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1. Document information

1.1. Abbreviation list

Abbreviation	Meaning
BOS	Balance of system
EU	Europe
EURAC	European Research Academy
GHG	Greenhouse gas
IMEC	Interuniversitair Micro-Electronica Centrum
KPI	Key performance indicators
NECP	National Energy and Climate Plans
PV	Photovoltaic
SBB	Südtiroler Bauernbund
SDG	Sustainable development goals
UAA	Utilised Agricultural Area
UPC	Universitat Politècnica de Catalunya

1.2. Description of the deliverable contents

The present deliverable is part of the activity performed by EURAC within SYMBIOSYST Task 4.1, related to the sustainability and eco-design of an agrivoltaics field.
Aim of this activity is to define a set of relevant Key Performance Indicators (KPIs) to be used to measure the sustainability level of an agrivoltaic field. The early design tool developed within WP2 of the same project is here extended to the creation of a new sustainable assessment methodology. The methodology is also based on the innovative solutions for reliability and performance measurement investigated in WP3. The present KPI-based method is strictly related to crop-based agrivoltaics, but could potentially be extended in the future to be applied to other agrivoltaic filed types, or to other renewable energy projects. The KPIs developed during the project consider all the aspects of sustainability, but the focus of the present report is on the ethic, social, environmental, eco-design and agricultural aspects. The economic aspects are evaluated in Deliverable 7.3, and a more detailed evaluation of the impact on local communities and companies is presented instead in Deliverable 6.3.
After the most relevant sustainability-related KPIs were selected with the support of different experts, a questionnaire evaluation was built based on the selected KPIs, and a scoring method was associated with each question.
Each KPI is also associated to a Sustainable Development Goal (SDG), to ease and aggregate the visualization of the results.
Several agrivoltaics demonstrators will receive the questionnaire, fill it, and send it back to EURAC for the test the methodology. The demonstrators will receive the score results and will have the opportunity to provide their feedback on the methodology itself, for its improvement. The first batch of test will be performed by sending the questionnaire to agrivoltaic demonstrators internal to the SYMBIOSYST project, based on their feedback a first refinement of the questionnaire and associated KPI-based scoring method will follow. Then, a second version of the questionnaire will be sent to agrivoltaics demonstrators external to the project, for a further cycle of feedback and refinement of the methodology.

The present document is structured as follows: after a first introduction of the activity in Section 1, Section 2 represents an overview on the state of the art of the sustainability evaluation for agrivoltaics field, Section 3 includes then the full questionnaire, while Section 4 presents the KPIs used to evaluate each question with the associated scoring method. The final Section 5 summarizes the work and presents the next steps.

The questionnaire and associated scoring method will be publicly available on the SYMBIOSYST website, for consultation. Agrivoltaic field owners may use these documents as a guideline for a self-sustainability evaluation. Despite that, the reader should note that this methodology is not associated with the obtainment of a certification and cannot be considered warranty of sustainability itself, since it is based on a self-evaluation and not on a certified verification process.

1.3. Reference material

This study is closely related to several other key deliverables and tasks within the Symbiosyst project. Together, these interconnected studies and tasks create a holistic framework for evaluating and enhancing the sustainability of agrivoltaic systems. In particular to the following project reports are linked to the present one:

- Deliverable 5.2, which includes the preliminary partial list of photovoltaic and agricultural KPIs, laid the groundwork for the comprehensive KPI framework developed in this study.
- The Symbiosyst Position Paper provided foundational insights and context that informed the overall approach to sustainability assessment.
- Deliverable 6.3 on social acceptance played a crucial role, as its methodology and results were used to refine the social KPIs, ensuring they accurately reflect stakeholder concerns and social dynamics.
- Deliverable 7 focus on the techno-economic aspects of sustainability, that will complement the KPIs related to the agricultural, social, and photovoltaic.
- Deliverable 4.2 will include the results of the environmental LCA of the entire SYMBIOSYST system model.
- Deliverable 4.4 will merge the results of both the environmental LCA and KPI-based sustainability assessment, as applied to the demonstrators

1.4. List of Figures

1.5. List of Tables

2. Agrivoltaics sustainability state of the art

The SYMBIOSYST project explores the integration of photovoltaic (PV) systems with agricultural practices, a concept well known as agrivoltaics. The innovation of this approach stands in the maximization of land use efficiency by combining solar energy production with agricultural activities, thereby supporting the energy transition while preserving and enhancing agricultural productivity.

Agrivoltaic systems offer several key benefits, in fact the PV panels can provide enhanced crop protection, offering shade and protection, potentially reducing water usage and defending plants from extreme weather conditions. Additionally, the dual use of land can lead to higher overall renewable energy production, contributing to reach renewable energy increase targets. However, there are several challenges associated with this technology, since different crops and climatic regions require specific agrivoltaic solutions to ensure the compatibility with the agricultural land and effectiveness of the system. Moreover, the adoption of agrivoltaics can have significant socio-economic effects on farming and local communities, necessitating careful consideration and planning.

The SYMBIOSYST project emphasizes the importance of continuous innovation and monitoring, to ensure a fruitful cooperation between solar energy and agricultural land, with a sustainable design of this integration, leading to a positive acceptance by all the involved stakeholders. The present study aims to fill the need to increased research efforts, supportive policies, and collaboration among stakeholders to promote a sustainable widespread adoption of agrivoltaics in Europe.

The SYMBIOSYST project believes that it is important to support the renewable energy production, maintain agricultural productivity and quality at the same time, but this must come with tailored designs, socio-economic considerations, and collaborative efforts to realize the full potential of this innovative technology [1].

Focusing on the European Union (EU), Solar Energy Strategy [2], the aim is to add 450 GWp of photovoltaic capacity between 2021 and 2030, necessitating an approximate fourfold increase to over 720 GWp by 2030. Around 50% of this new capacity is anticipated to be installed as ground-mounted systems in agricultural areas, meaning that the potential for agrivoltaics in the EU is substantial. In fact, covering just 1% of Utilised Agricultural Area (UAA) with agrivoltaic systems could generate approximately 944 GW, assuming an installed capacity of 0.6 MW/ha. This is about half the output of traditional ground-mounted PV systems (around 1,809 GW) and nearly five times the EU's installed capacity in 2022, and the New Policy Trends National Energy and Climate Plans (NECP) [3] PV target for 2030 can be met with only 0.6% UAA coverage [4].

In this context, assessing the sustainability of an agrivoltaic field is essential because it ensures that the combination of agricultural and solar energy systems is not only economically viable but also socially and environmentally responsible. This evaluation helps identifying and addressing potential negative impacts on biodiversity, soil health, and local communities, along the full lifecycle of the agrivoltaics value chain. It also optimizes the efficiency and durability of both agricultural and photovoltaic components, supporting food security and renewable energy objectives [5].

Using lifecycle-based techniques to assess the sustainability of agrivoltaic systems is crucial because it provides a proper understanding of the environmental, social, and economic impacts throughout the entire lifespan of both photovoltaic and agricultural components.

Traditional environmental Life Cycle Assessments (LCA) generally focus their attention purely on environmental impacts. When going from a pure environmental LCA, to a wider life cycle sustainability assessment (LCSA) there is currently a lack of methodological harmonization, especially for a multi-output system such as the agrivoltaic one.

The advantage of integrating the LCA analysis with more holistic KPI-based approach, is that also other aspects of sustainability, such as social, electrical an agricultural need, are considered. In this way, all the value chain stages—from production and installation to operation, maintenance, and end-of-life disposal.

Furthermore, the KPIs are specifically selected considering the needs of all the stakeholders along the value chain, from the farmers to the local communities, to the producers of raw materials or waste management operators.

By doing so, this approach can help to identify opportunities for improvement, reduce negative impacts, and enhance the overall sustainability of agrivoltaic systems.

The integration of the present KPI-based methodology with the results of the environmental LCA assessment – that will be available in Deliverable 4.2 – will offer a robust framework for assessing the sustainability of agrivoltaic systems, ensuring that both specific stakeholder-based performance metrics and comprehensive environmental impacts are considered.
This holistic method wants to help preventing misconceptions and alleviates public concerns about agrivoltaics, fostering trust and acceptance among the public. A representative illustration of key aspects related to agrivoltaics sustainability is illustrated in Figure 1.

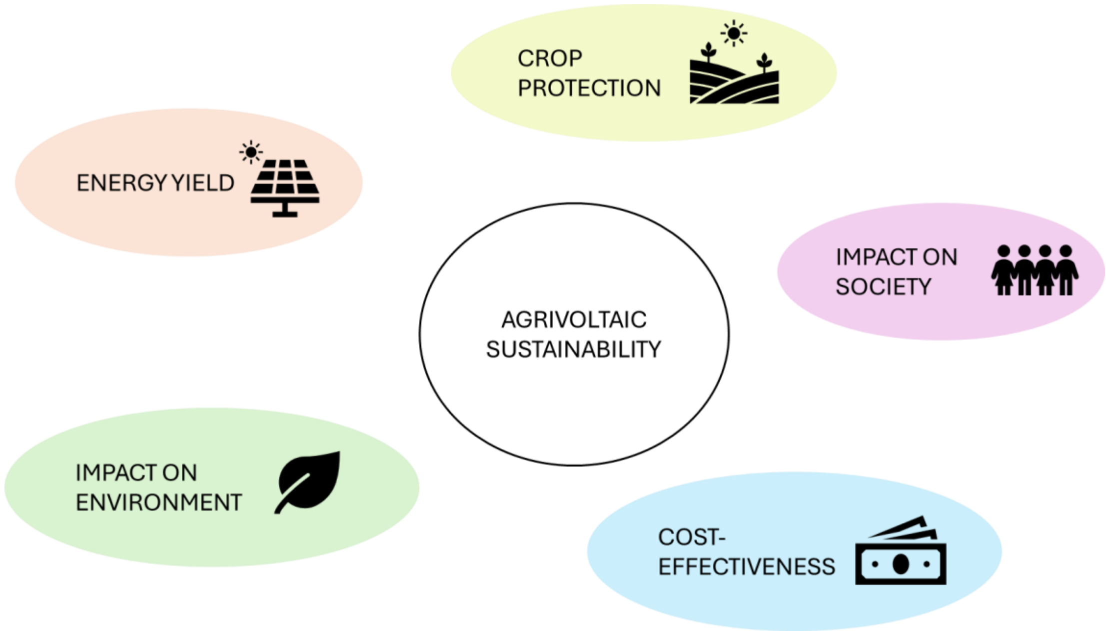


Figure 1 Representation of the key aspects related to agrivoltaics sustainability

One of the first key aspect to consider for ensuring an eco-friendly and sustainable design, is the crop-protection. In fact, an agrivoltaics field must be design ensuring that crops receive the necessary amount of sunlight for optimal growth. This involves careful selection, planning and positioning of PV panels to balance energy production with agricultural needs. Additionally, it is crucial that the presence of PV panels does not hinder machinery operations required for planting, maintaining, and harvesting crops. Similarly, the machinery used for cleaning and inspecting the PV modules must operate without disrupting agricultural activities. Integration can be further enhanced by using ad-hoc designed PV panels, with varying heights, transparent backsheets, more dispersed PV cells, or effective use of PV optimized tracking systems. These design modifications allow for better light penetration and adaptability to different crop types and farming practices, ensuring that both energy generation and agricultural operations can coexist efficiently and sustainably.
While agrivoltaic systems offer several benefits, if not properly designed, they can also negatively impact agriculture, electricity production, environment and society. One of the major issues is the potential reduction in crop yields due to the shading effect of PV panels, which can alter sunlight and soil moisture patterns essential for optimal plant growth. Furthermore, the integration of energy production and agriculture can increase socio-economic disparities, particularly in regions where small-scale farmers may lack the resources to adopt such systems [5].

A wide and comprehensive report on agrivoltaics sustainability, that was taken as major reference for this document, is represented by the Solar Power Europe Report of 2023 [6], highlighting the best practices guidelines specific for the agrivoltaics sector.
On the other hand, the integration between crops and PV energy systems can improve crop yields, soil health, and water efficiency, while also promoting biodiversity by providing habitats for various species. In fact, PV modules can offer protection to crops from extreme weather conditions, retaining humidity and reducing their water need, thereby increasing agricultural resilience. The environmental impact of agrivoltaic systems on the carbon footprint is notably

positive, as they reduce the GHG emissions by producing renewable energy [6]. A more comprehensive LCA analysis of the environmental impact of agrivoltaics systems of the Symbiosyst project will be available in Deliverable 4.2, and finally, the results from the LCA and the present KPI based methodology assessment will be merged and summarized together in Deliverable 4.4.

3. Sustainability evaluation questionnaire

In the present Section 3, the new developed questionnaire to evaluate the sustainability level of an agrivoltaic system is explained and presented. The questionnaire was written thanks to the collaboration of experts in photovoltaic, agriculture, biodiversity, social responsibility and survey development sectors. It was created as part of Task 4.1 activities, by the project partners EURAC, UPC, EF SOLARE, IMEC, CONVERT. The present methodology is meant to be useful for different kind of crop based agrivoltaic fields, both open and closed, large scale or small scale.
The target for this study includes agrivoltaic-related stakeholders such as farmers, PV producers and installers, policymakers, and local communities. By engaging these diverse groups, the study aims to provide valuable insights and practical tools that support the sustainable development and public acceptance of this type of systems.
In this report, we focus specifically on agrivoltaic systems related to crop cultivation, whether in open fields or closed greenhouses. However, the methodology is versatile and can be further refined and extended to other types of crops and agricultural setups.

The questionnaire is composed by 66 questions, divided into four sections, as follows:

- 11 questions to collect agrivoltaic field information (Section 3.2)
- 16 questions related to the social sustainability (Section 3.3)
- 20 questions related to the sustainability of the photovoltaic system (Section 3.4)
- 20 questions related to the sustainability of the agricultural system (Section 3.5)

The first set of questions are meant to screen the information on the type of agrivoltaic field. This is useful to aggregate the results that will be obtained from the questionnaire, by agrivotlaic field type.
The second section of questions is intended to evaluate the social responsibility of an agrivoltaics owner, including – as an example - aspects from the social acceptance and stakeholder engagement already during the design phase of an agrivoltaic project, to the screening of the suppliers to guarantee a transparent supply chain, to the respect of human rights and fair working conditions. The sustainability of the photovoltaic system is evaluated thanks to the third section of questions, to make sure that PV components and associated Balance of System (BOS) that are installed in the agrivoltaic field are highly efficient, durable, properly integrated to ensure an adequate amount of light for the crops, and sustainably produced.
Finally, last set of questions are intended to measure the sustainability of the agricultural production, to make sure that the quality of the plant and crop under the PV panel is as good as the quality of the crop in a traditional agricultural field without PV integration, but also to ensure that biodiversity is respected, and that the machinery operations on the field are not complicated by the PV system.
For the three social, photovoltaic and agricultural categories, the questions can be further divided into several more specific sub-categories (e.g., diversity and gender equality, health and safety, etc.)
The document is meant to stay publicly available in the public SYMBIOSYST webpage [7], together with the associated scoring method, so that agrivoltaic plants owners can use it as an auto-evaluation. To the date of this report, the questionnaire has been sent to six agrivoltaic plant demonstrators within SYMBIOSYST, for a first test. The questionnaire is meant to be filled by different people involved in the agrivoltaic field, with different expertises, who can take around one/two months or more to answer the questions and provide their feedback. After this first round of test and feedback, the methodology will be refined. The refined questionnaire will be then sent to the demonstrators (about 10-20 already selected demonstrators) external to SYMBIOSYST project, that were selected thanks to a series of workshops performed during the project.
Each question is associated to a KPI, and each KPI is further associated to an SDG, which will be used to provide a score. Based on the KPIs and scoring method associated to each question, the answers provided will be evaluated by EURAC, that will send back the evaluated results to the agrivoltaic field owners. The procedure to test the questionnaire with the agrivoltaics demonstrators is schematized in Figure 2, while the first draft of the questionnaire and the full table of the KPIs and scoring method are available respectively in ANNEX I and ANNEX II, at the end of the present deliverable.

The results of the first tests will be collected, aggregated and presented in the Deliverable 4.4, together with the environmental assessment, due at the end of SYMBIOSYST project. Results of the questionnaire will be shared in an aggregated way, removing all possible sensible data.

Figure 2 Schematization of the procedure used to test the questionnaire with the agrivoltaic demonstrators

4. SDG-based KPIs and scoring method

4.1. KPIs selection and associated scoring method

In this section, the KPIs and scoring method associated to each question are presented and explained. Similarly to the sections of the questionnaire itself, since each question has an associated KPI, the KPIs can be divided into three sections: social, photovoltaic and agricultural. Each category can be divided in turn in different subcategories, reflecting the same structure of the questionnaire.
Each KPI is further associated to an SDG goal – as explained in Figure 3 and listed in Table 1 - in order to ease the visualization of results. Table 1 presents an example of visualization of the results, in association to the SDGs.
The following sections explains each of the three KPIs categories, while the full list is available in ANNEX II.

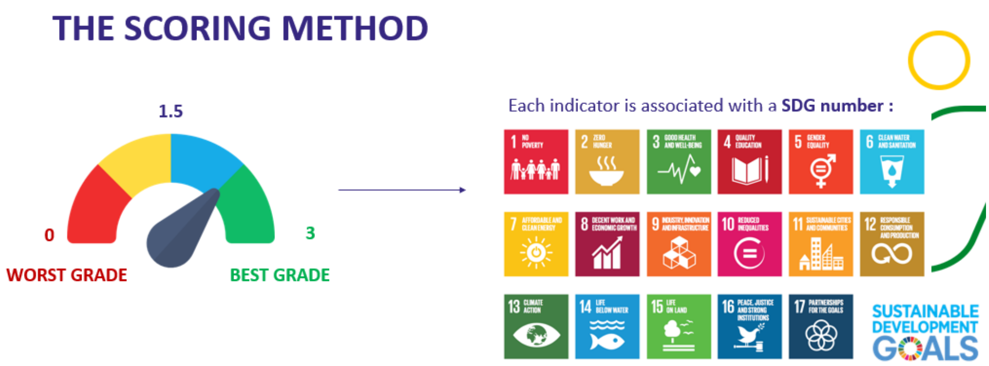


Figure 3 Illustration of the scoring method used to evaluate the selected KPIs, in association with the SDG goals.

Table 1 List of the sustainable Development Goals (SDGs) [8] associated with the KPIs used for the sustainability assessment, with an example of visualization of the final score.

SDG NUMBER	SDG NAME	DESCRIPTION	SCORE %
5	Gender Equality	Achieve gender equality and empower all women and girls	78%
6	Clean Water And Sanitation	Ensure availability and sustainable management of water and sanitation for all	67%
7	Affordable And Clean Energy	Ensure access to affordable, reliable, sustainable, and modern energy for all	50%
8	Decent Work And Economic Growth	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all	67%
9	Industry, Innovation, And Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation	67%
11	Sustainable Cities And Communities	Make cities and human settlements inclusive, safe, resilient, and sustainable	89%
12	Responsible Consumption And Production	Ensure sustainable consumption and production patterns	76%
13	Climate Action	Take urgent action to combat climate change and its impacts	67%
15	Life On Land	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reserve land degradation and halt biodiversity loss	65%
		TOTAL SCORE	***69%***

The maximum total points associated to the questionnaire is 186 points: 36 maximum points associated to the PV social section, 61 to the photovoltaic section and 89 to the agricultural section. Majority of the questions can have a minimum score of zero, and a maximum score of three, while a few questions have "cumulative" points with a maximum of 3, 4 or 5 points each. The details of the maximum score associated to each question is provided in Sections 4.2, 4.3, 4.4. After the first test with the demonstrator, the KPIs and associated scoring method can be further refined with the obtained feedback. Eventually, a weighting system for the KPIs can be added to better aggregate the results. Results can be visualized also without using the SDG aggregation, as in the example in Table 2.

Table 2 Example of visualization of results, without using the link with the SDGs

SECTION	SCORE %
SOCIAL	78%
PHOTOVOLTAIC	67%
AGRICULTURAL	66%
TOTAL POINTS OBTAINED	**69%**

4.2. Social KPIs

Social KPIs were developed thanks to the support of social science experts within EURAC, who worked in the activities in WP6. These KPIs are based on available guidelines at European level [9], on the SDG goals [8], and on guidelines from the United Nations [10]. The primary challenge in addressing social aspects is that they are inherently qualitative, making them difficult to measure quantitatively.

The selected indicators include the gender equality rate among workers and the presence of gender equality plans, which ensure fair representation and opportunities for all genders. But also, health and safety policies and practices are crucial for maintaining a safe working environment, ensuring fair labor policies and practices for all the workers involved in the supply chain. In the methodology, the agrivoltaics plants which can provide health, safety and fair labor policies that go beyond legal requirements are rewarded with a higher score. Furthermore, indicators consider if the suppliers are selected previa a social screening, that helps maintain ethical standards throughout the supply chain including the first stages.

Another relevant aspect measured by the social KPIs is the quality of the stakeholder engagement process. This sub-category of indicators was created with the support of the work performed by EURAC in WP6, related to the social acceptance of agrivoltaics. In fact, for a success of an agrivoltaics project it is important to engage the most relevant stakeholders already in the early design phase, by collecting their opinion and by using the collected opinion in the decisional phases of the plant design. Since the stakeholder categories can vary from plant to plant, the KPIs related to this sub-category are listed in a separate matrix (available in ANNEX II), which aims to reflect the inclusivity and engagement of diverse groups in the project. Involvement in energy communities is rewarded as well, as a commitment to collaborative with community-based energy solutions.

Additionally, certifications or labels obtained by the organization for their agricultural products are recognized as observance of quality and sustainability, while the presence of communication and training programs on gender equality, human rights, and social responsibility highlights the organization's dedication to fostering an inclusive and ethically aware culture.

The full list of social KPIs, together with the stakeholder evaluation matrix is available in Table 4 in ANNEX II, at the end of the present document.

4.3. Photovoltaic KPIs

Photovoltaic KPIs are based on the feedback from experts within EURAC, IMEC, UPC and EF Solare, in collaboration with WP2, 3 and 5.
These sustainability indicators were selected based on a variety of sources, such as input from industry best practices, academic research, and regulatory guidelines such as Solar Power Europe Best Practices [6] and the Italian National Guidelines [11] for agrivoltaics systems, that were the main references used to understand the proper indicators for this section.
The comprehensive set of indicators addresses various aspects of material sourcing, environmental impact, and operational efficiency. Material sourcing is assessed for PV cells and wafers, PV modules, and Balance of System (BOS) components, to ensure responsible procurement practices. Additionally, environmental screening of PV modules and BOS components helps identify and mitigate potential environmental impacts along the value chain. The reuse of PV modules and the use of recycled input materials, measured by weight, is also rewarded to promote circular economy. Moreover, an end-of-life management plan for PV systems is crucial for sustainable disposal and recycling of components, with specific indicators that rewards if the end-of-waste routes for PV modules and BOS components are well known, and if they favour recycling paths, beyond legal requirements. Furthermore, PV module efficiency, electricity coverage, tracking system optimization and PV module temperature are monitored to enhance operational performance.
Greenhouse gas (GHG) emissions are tracked for both PV modules and BOS production to minimize the carbon footprint. The impact of landscape integration measures is also evaluated to ensure harmonious coexistence with the environment. Finally, communication on environmental sustainability, both within and outside the organization, is essential for transparency and stakeholder engagement. A full list of the photovoltaic KPIs is available in ANNEX II, in Table 6.

4.4. Agricultural KPIs

The agricultural indicators are designed to cover a wide range of aspects varying from crop quality to water management, to continuous operation of agricultural machinery. This set of indicators were identified based within the SYMBIOSYST project based on the support and feedback of agricultural experts involved inside the consortium as agrivoltaic demonstrators, such as UPC, EF Solare, LAIMBURG, KUBO, KU Leuven, Engie-Lab, SBB that will also test the first draft of the questionnaire and provide feedback. The set of indicators is also based on the experience in the innovative design and solutions for agrivoltaics from WP2 and WP3, together with the novel sensors tailored to agrivoltaics measurements investigated in WP5.
In this part of the assessment, the agrivoltaics field is compared with a traditional field without PV integrated, and the effect of the PV covering is analysed in a comprehensive way. The quality of crops is a key indicator, ensuring that the presence of PV panels does not negatively impact agricultural productivity.
These indicators measures the impact on the agricultural system, including soil health, water usage, and carbon footprint.
Among the most important agricultural indicators, the plant phenology plays a crucial role, encompassing various stages of plant development. Plant vigor is assessed through metrics such as plant/sprout height and diameter, which provide insights into the overall health and robustness of the plants. Additionally, the number of fruits (or pods) per plant is a vital indicator of reproductive success and yield potential. Another important aspect of plant health is the measurement of photosynthetically active radiation (PAR), which indicates the amount of light available for photosynthesis, directly influencing plant growth and productivity. Postharvest quality traits are equally significant, ensuring that the produce meets market standards and consumer expectations. These traits include the average fruit/vegetable diameter and weight, which are critical for grading and packaging. The sugar content and acidity of the agricultural products are measured to determine taste and nutritional value, while the external appearance is evaluated to ensure visual appeal, and a market standard fit check is conducted to verify that the produce meets the required specifications for sale. Soil health is also monitored through indicators such as soil pH and soil temperature, which affect nutrient availability and root development.

Biodiversity maintenance is another crucial aspect for open field plants, as it ensures that the agrivoltaic system supports and enhance a healthy ecosystem, promoting the presence of various plant and animal species. The indicators related to biodiversity were selected thanks to the feedback of EURAC Biodiversity department.

Furthermore, the operation of agricultural machinery is evaluated to ensure that the integration of PV systems does not hinder the movement of necessary machinery activity.

The full list of the agricultural KPIs is available in ANNEX II, in Table 7.

5. Summary and next steps

To summarize and draft conclusions, the present report aims to create a holistic lifecycle and KPI-based methodology for evaluating the sustainability of specific agrivoltaic projects. Together with the environmental LCA analysis, the techno-economic assessments and the social implications investigated in the other work packages of the SYMBIOSYST project, will bring to a comprehensive understanding of the impacts of agrivoltaic system on the environment, the economy and the stakeholders.
This wide approach ensures that the benefits of agrivoltaic systems are maximized. while maintaining high standards of environmental protection and social responsibility, supporting the dual use of land for agriculture and renewable energy production, but warrantying at the same time the protection of land and the promotion of environmental sustainability.

A significant obstacle encountered related to this activity is linked to the complexity of accuracy in the sustainability measurement of agrivoltaic systems, given their multifaceted nature. Balancing the diverse aspects of environmental, social, and economic impacts requires a comprehensive and variegated approach, which can be difficult to achieve. Additionally, gathering active participation of the various stakeholders and ensuring their engagement in the evaluation will be a major challenge of the testing phase of the methodology.
Addressing sustainability in agrivoltaics is further complicated by the fact that agrivoltaic landowners are often small farmers that - unlike large companies - typically lack the budget and resources to manage sustainability aspects effectively. This risking to lead to disparities between large and small-scale applications.
Another obstacle was encountered at policy level, which is the lack of harmonized legal procedures for agrivoltaic installations: this would be a crucial step to facilitate the agrivoltaic systems installation, at least at the EU level. By including sustainability aspects when establishing new regulations, it can be possible to ensure safety, environmental protection, and agricultural productivity. This harmonization should simplify the verification process, making it more efficient and less costly for farmers and developers to implement these systems across different countries.

At the time of this report submission, the questionnaire has been distributed to six agrivoltaic demonstrators within the project, to test the methodology and gather their feedback. The next steps of the activity will involve the refinement of the questionnaire and the associated scoring method, based on the received feedback. This refined version of the questionnaire will then be sent to additional agrivoltaic demonstrators outside the SYMBIOSYST project for a further iterative step of testing, feedback and refinement. This iterative process will continue until the methodology is well-validated and reliable, to ensure that the method is robust and applicable by other agrivoltaic field owners as a self-assessment, but also across different contexts and regions.
The methodology's potential extends beyond crop-based agrivoltaics fields, offering a model for evaluating other types of agrivoltaics project such as animal farming, or other type of renewable energy projects, after extending the scope of the questions and relevant KPIs.

ANNEX I – Sustainable agrivoltaic evaluation questionnaire

A1.1. Agrivoltaic field information

1.
Name of agrivoltaics field or company

2.
Location of agrivoltaic field (city, country)

3.
Dimension of agrivoltaic field in hectares

4.
What is the main purpose of the agrivoltaic field?
☐ Experimental/ research
☐ Perform agricultural activity
☐ Produce electricity
☐ Other, please specify:

5.
Type of land:
☐ Owned land
☐ Rented land
☐ Other, please specify:

6.
Average number of workers such as farmers, other employees involved in the agrivoltaic field over the course of a year:

7.
Is the agrivoltaic field part of a consortium, or is this in program?
☐ Do not know
☐ No
☐ In program[1]
☐ Yes, please provide the name of the consortium:

8.
If the agrivoltaic field is part of a consortium, have you received any kind of support on the agrivoltaic management and installation? If the agrivoltaic field is NOT part of a consortium, please leave this section blank
☐ No, no support received on the agrivoltaics management and installation
☐ Yes, please specify:

9.
Type of agrivoltaic field
☐ Open ground field
☐ Closed field (greenhouse)
☐ Grassland
☐ Livestock farming
☐ Other, please specify:

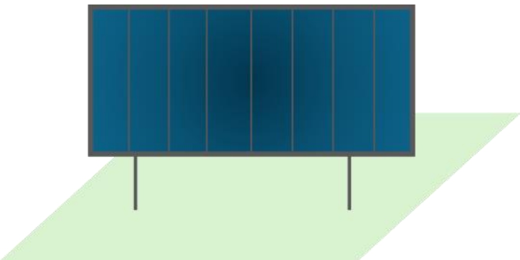
10.
If your agrivoltaic field is devoted to agriculture or livestock farming, please specify the type of crops/animals (e.g. horticulture and peach trees). Otherwise, leave this question blank

[1] Activity that is planned within one year from the date of filling the questionnaire. The planning of the activity needs to be demonstrable by means of written documentation, public announcements, organization meeting, etc.

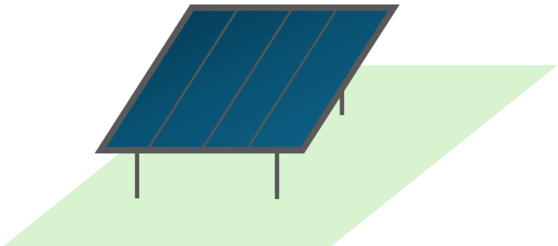
11.

PV structure type

☐ Vertical PV



☐ Horizontal PV



☐ Other types. Please describe:

A1.2. Social sustainability questions

Diversity and gender equality

12.
What is the percentage of **women** working in the agrivoltaic field (e.g. owners, farmers, other)?

☐ Do not know

☐ Please, specify:

13.
Are there written measurements in place or in program to improve the **gender gap** of the workers in the agrivoltaic plant (e.g., is there a gender equality plan, or/and a transparent declaration of the gender data)?

☐ Do not know

☐ No

☐ In program1, please specify and provide details on the timeline:

☐ Yes, please specify:

Health and safety

14.
Are there written plans of action in place or in program, regarding **health and safety** (e.g., regarding risk assessments, hazard analysis, trainings for workers to prevent workplace-related injuries or illnesses).

☐ Do not know

☐ No

☐ Yes

If yes, please select the option that best describes your situation:

☐ Health and Safety measurements are compliant with local legislation

☐ There are health and safety measurements in addition to those required by the local legislation already in place. Please specify:

☐ There are additional health and safety measurements in program1, other than the ones required by local legislation. Please specify:

Fair labor and human rights

15.
Are there written plans of action in place or in program, regarding **fair treatment and human rights** for workers involved in the agrivoltaic plant (e.g., written code of conduct against illegal labor, plans including fair wages, fair working hours, equal opportunities for all workers, freedom of association, guaranteed health insurance)?

☐ Do not know
☐ No
☐ Yes

If yes, please select the option that best describes your situation:

☐ Fair labor and human rights measurements are in place, and they are compliant with local legislation
☐ There are measurements related to fair labour and human rights, in addition to those required by the local legislation already **in place**. Please specify:

☐ There are measurements related to fair labor and human rights, in addition to those required by the local legislation **in program1**. Please specify

Social responsibility of suppliers

16.
Are the **agricultural suppliers** (e.g., suppliers of seeds, fertilizers, machinery, agricultural equipment, etc.) chosen according to their social responsibility?

☐ Do not know
☐ No
☐ Yes

If yes, please **select** the option that best describes your situation:

☐ Only suppliers who are socially sustainable are chosen. Please, provide details on the supplier screening method (e.g., which specific certifications are required, level of transparency of the supply chain that is required)

☐ Socially sustainable suppliers are prioritized. Please, provide more details on the supplier screening method (e.g., which specific certifications are required, level of transparency of the supply chain is required):

☐ Other, please specify:

Stakeholder engagement

17-22.
See Table 3 for questions related to stakeholders engagement (6 questions for each stakeholder)

Table 3 Stakeholder engagement evaluation matrix, related to questions 17-22. Please fill the table based on the stakeholder engagement process related to your agrivoltaics field.

STAKEHOLDER NUMBER	**17. STAKEHOLDER CATEGORY**	**18. STAKEHOLDER DESCRIPTION (please, provide more information on the stakeholders that were engaged. E.g., neighborhood farmers, farmers of the same consortium, local policy makers, local citizens, local shop owners)**	**19. ENGAGEMENT TYPE (PASSIVE = informative on agrivoltaic topic or ACTIVE = with involvement in activities aimed to collect opinion or consent on the agrivoltaic topic)**	**20. ENGAGEMENT METHOD (e.g., surveys, lessons, interviews, workshops, webinars, seminars)**	**20. IN WHICH PHASE WAS THE STAKEHOLDER ENGAGED? (In the agrivoltaic design phase or after the agrivoltaic plant was built)**	**23. IF THE STAKEHOLDERS' OPINION WAS COLLECTED, WAS THEIR OPINION TAKEN INTO ACCOUNT IN THE DECISIONAL PHASE OF THE AGRIVOLTAIC PLANT'S CONSTRUCTION? IF YES, PLEASE DESCRIBE HOW**
1	Farmers - involved in the agrivoltaic field					
2	Farmers - others than the ones involved in the agrivoltaic field					
3	Citizens					
4	Local community					
5	Local authorities					
6	*Insert any others*					
7						
8						

Product certification

23.
Does the agrivoltaics field have any **certification related to the** social responsibility of the agricultural product it produces (e.g., fair trade), or is a certification in program?

☐ Do not know

☐ No

☐ In program1. Please specify the type of certification in program:

☐ Yes. Please specify:

Energy community

24.
Is the agrivoltaic field part of an **energy community,** or is it in program?

☐ Do not know

☐ No

☐ In program1

☐ Yes

Communication and transparency

25.
Is the **gender equality plan** transparently communicated internally and externally of the organization, or/and are there internal trainings on the topic, or are either planned?

☐ Do not know

☐ Gender equality plan not available

☐ No

☐ In program1, please specify how:

D☐ Yes, please specify how:

26.
Are written plans of action in place or in program, regarding **fair treatment and human rights** of workers transparently communicated inside and outside the organization, or/and are there internal trainings on the topic? If not, are they planned?

☐ Do not know

☐ Written plan of action regarding fair treatment and human rights not available

☐ No

☐ In program1, please specify how:

☐ Yes, please specify how:

27.
Are the **social responsibility** measurements (e.g., by means of a certification) transparently communicated and/or are there internal trainings on the topic, outside the organization, or are they it planned?

☐ Do not know
☐ No
☐ No certified social responsibility measurement
☐ In program1, please specify how:

☐ Yes, please specify how:

A1.3. Photovoltaic questions

Materials

28.
Where are the **PV modules** manufactured? Please specify the PV module manufacturer and/or its manufacturing country or region

29.
Where are the **PV cells and wafers** manufactured? Please specify the PV cells and wafer manufacturer and/or its manufacturing country/region

30.
Where are the **Balance of System (BOS) components** manufactured? Please specify the manufacturing country/region of each of the following BOS components: inverters, mounting structure, trackers, batteries, other auxiliary equipment in addition to the PV module

Environmental screening of suppliers

31.
Are the **suppliers of PV module** checked in terms of environmental sustainability (e.g., are they required to have an environmental certification/ label), or is this activity in program?

☐ Do not know

☐ No

☐ In program1. Please specify the type of screening and its timeline if planned1:

☐ Yes, please specify the type of screening:

32.
Are the **suppliers of Balance of System (BOS) components** checked in terms of environmental sustainability, or is this activity in program? (e.g., are they required to have an environmental certification/ label?)
BOS components: inverters, mounting structure, trackers, batteries, other auxiliary equipment in addition to the PV module

☐ Do not know

☐ No

☐ Please specify the type of screening and its timeline if in program:

☐ Yes, please specify:

Circularity and eco-design

33.
At the end of its lifetime, are PV modules tested to be **reused** in the second-hand PV market, or is this activity in program?

☐ Do not know

☐ In program1. Please specify the type of test and its timeline if it is planned1:

☐ Yes, please specify the type of test:

34.
Are **recycled materials** used to produce the agrivoltaic system's PV modules?
This information can be obtained from the PV module supplier, information sheet, or in the Environmental Product Declaration (EPD) of the product, if available.

☐ Do not know

☐ No

☐ Yes, please specify:

End-of-life

35.
Are you informed about the **end of life of the PV modules** installed in the agrivoltaics field?
This information may be available from the PV module supplier.

☐ No

☐ Yes, the PV module will be taken to an electronic waste center, in accordance with the WEEE directive, but I have no information on the materials that will be recycled.

☐ Yes, the PV module will be sent to a recycling center specific for PV modules.

☐ Yes, the PV module will be treated in a recycling center for general electronic, glass or other waste. Please specify:

36.
If the PV module will be sent to a **recycling center specific for PV modules**, please specify the materials that will be recycled, and their second life purpose.
Multiple answers are allowed.

☐ Do not know

☐ Copper from the cables will be recycled to produce secondary copper

☐ Aluminium from the frame will be recycled to produce secondary aluminium

☐ Glass will be recycled. Please specify the secondary product (e.g., solar glass, foam glass, window glass)

☐ Silicon in the PV cell will be is recycled. Please specify the secondary product (e.g., metallurgical silicon, solar grade silicon, insulation material)

☐ Other materials. Please specify:

37.
Are you informed about the **end of life of the Balance of System (BOS) components** installed in the agrivoltaics field you are affiliated with/work in?
BOS components are: inverters, mounting structure, trackers, batteries, other auxiliary equipment in addition to the PV module.
This information may be available from BOS component suppliers.

☐ No,

☐ Yes, the BOS components will be collected following the component-specific directive at the end of their life, but I have no information on the materials that will be recycled.

☐ Yes, the BOS components will be sent to a specific recycling center at the end of their life. Please specify the type of recycling center.

☐ Something else will happen to the BOS components at the end of their life. Please specify:

Electrical efficiency

38.
What is the **PV module's efficiency** in STC (Standard Testing Conditions)[2] as expressed in kWp/m2 of PV module? This information may be available in the PV module information sheet.

☐ Do not know.

☐ Do not know the exact value. Please specify the type of PV module (e.g., mono crystalline silicon, bifacial, single glass, etc.)

☐ Please insert the PV module's efficiency [kWp/m2]

39.
What amount of the annual electricity consumption required by the farm (e.g., light, irrigation, charging of electric machines) is covered by PV electricity.

☐ Do not know

☐ Please specify the share of the annual electricity consumption. Please specify which facilities are included in the farm's consumption. (e.g., lights, agricultural machinery, food processing processes, irrigation, etc.)

40.
Are there optimized **tracking algorithms** in place (i.e. trackers) to maximize energy production?

☐ Do not know

☐ Yes, the mounting structures are provided with trackers

☐ No

41.
Which of the following apply to your agrivoltaics system in relation to the **temperature** of the PV module:
Multiple answers are allowed.

☐ The surface temperature of the PV modules is not monitored

☐ The surface temperature of the PV modules is monitored, and the temperature is lower than a non-agrivoltaic PV module. Please provide more details:

☐ The surface temperature of the PV modules is monitored, and the temperature is generally higher than a non-agrivoltaic PV module. Please provide more details:

☐ Other, please specify:

[2] STC is an industry-standard set of parameters used to evaluate solar panel performance: solar irradiance: 1,000 watts per square meter (W/m²) and cell temperature: 25°1.5

Greenhouse gas emissions

42.
Please indicate the greenhouse gas (GHG) emissions in terms of their CO2-equivalent in kilograms (kg CO2-eq) which are emitted during the **PV module's** lifetime, per kWp installed.
This information may be available from the PV supplier, if the PV supplier has carried out an Environmental Product Declaration (EPD).

☐ Do not know

☐ Please specify the amount, unit, and any other details (e.g., kg CO2-eq/kWp for a PV module manufactured in China, excluding mounting structure, information provided from product EPD):

43.
Please indicate the greenhouse gas (GHG) emissions in terms of CO2-equivalent in kilograms (kg CO2-eq) which are emitted during production of the **BOS components** (e.g., mounting structure, inverter, trackers, battery).
This information may be available from the BOS suppliers, if suppliers have performed an Environmental product Declaration (EPD).

☐ Do not know

☐ Please specify the amount, unit, and any other details (e.g., kg CO2-eq for a 2.5 kW inverter, manufactured in China, information provided from product EPD):

Landscape integration

44.
What is local stakeholder **perception** of the visive impact of the agrivoltaics field (e.g., neighbouring farmers, shops, citizens?

☐ Do not know

☐ Mostly positive. Please specify how the perception was measured (e.g., via surveys, direct interviews):

☐ Mostly negative. Please specify how the perception was measured (e.g., via surveys, direct interviews):

☐ Mostly neutral. Please specify how the perception was measured (e.g., via surveys, direct interviews):

45.
Are there **measurements** in place or in program, to better integrate the agrivoltaic system into its landscape (e.g., semi-transparent PV modules, colour PV modules)?

☐ Do not know

☐ No

☐ In program1. Please specify provide details on their timeline:

☐ Yes. Please specify:

Communication

46.
Are policies regarding environmental sustainability measurements transparently **communicated internally**, and/or are there internal trainings on the topic within your agrivoltaics organization? Or is this activity in program? (e.g., annual reports, monthly internal meetings, internal courses, etc.)

☐ Do not know

☐ No

☐ In program1. Please specify the type of communication and their timeline:

☐ Yes. Please specify the type of communication:

47.
Are the policies regarding environmental sustainability measurements transparently **communicated externally** and/or are there internal trainings on the topic, outside your agrivoltaics organization? Or is this activity in program? (e.g., annual reports, monthly workshops, webinars, social media, etc.)

☐ Do not know

☐ No

☐ In program1. Please specify the type of communication, and its timeline:

☐ Yes. Please specify the type of communication:

A1.4. Agricultural questions

End-of-life of agricultural field

48.
Is there a sustainable **restoration plan** in place or in program for the agrivoltaic field at the end of its lifetime?

☐ Do not know

☐ No, there is no restoration plan

☐ In program1. Please specify the restoration plan and its timeline:

☐ Yes. Please specify the restoration plan:

49.
Is there an energetic **valorization of agricultural waste** (e.g., annual pruning) practice in place or in program?

☐ Do not know

☐ No

☐ In program1. Please specify the valorization action and its timeline:

☐ Yes. Please specify the valorization action:

Water management

50.
Is less **water needed** in your agrivoltaic field (agricultural consumption of irrigation water only) than in one of a control area without agrivoltaics?

☐ Do not know

☐ No, the water needed by the crop is the same. Please, specify the measurement method used (e.g., humidity level of soil, m3 of irrigation water)

☐ Yes, there is a decrease in the water needed by the crop under the agrivoltaic modules. Please, specify the difference and the measurement method used (e.g., humidity level of soil, m3 of irrigation water)

☐ Other, please specify:

51.
Is there a **rainwater recovery system** in place or in program?

☐ Do not know

☐ No

☐ In program1, the agrivoltaics PV system will be integrated with a rainwater recovery system. Please provide details on the type and capacity of the system and its timeline:

☐ Yes, the agrivoltaics PV system has an integrated rainwater recovery system. Please provide details on the type and capacity of the system:

☐ Other, please specify:

Land use

52.
What is the **Land Area Occupation Ratio (LAOR)** of the agrivoltaics field?
The LAOR is defined as the ratio between the area occupied by PV system (S_{pv}) and the total area of the agrivoltaic system (S_{tot})?
Definitions:
S_{pv}= sum of the surfaces identified by the external profile of maximum size of all the PV modules constituting the system (active PV area including frame);
S_{tot}= area which includes the area used for crop and/or livestock farming and the total area on which the agrivoltaic plant stands

S_{pv}: S_{tot}: *LAOR*:

53.
What was the **land type before** the installation of the agrivoltaic field?

☐ Uncultivated land

☐ Agricultural field

☐ Photovoltaic field

☐ Other, please specify:

Biodiversity

54.
Is the **agrobiodiversity** of the agrivoltaics field monitored (e.g., certification/ label, use of different agricultural species, periodic rotation of culture to preserve soil quality, use of companion plants, etc.)? Or is this activity in program?

☐ Do not know

☐ No

☐ In program1. Please specify how preservation will be undertaken, and the timeline:

☐ Yes. Please specify how the agrobiodiversity is being preserved:

55.
(Only for open ground fields)
Are there measurements to **preserve and increase biodiversity** in your agrivoltaics field (e.g., non-cultivated areas, hedges, small ponds and rows of trees to increase the presence of pollinators and maintain the landscape) in place or are they in program?

☐ Do not know

☐ No

☐ In program1. Please specify the measurements and their timeline:

☐ Yes. Please specify:

56.
(Only for open ground fields)
Are measurements to **quantify the biodiversity** of the agrivoltaic field in place or are they in program?

☐ Do not know

☐ No

☐ In program1. Please provide details of the analysis planned and its timeline:

☐ Yes

If biodiversity measurements have been performed, please **indicate** if you have noticed any of the following:
Multiple answers are allowed.

☐ Do not know

☐ Difference in the amount and diversity of flowering, between the agrivoltaics field and a non-agrivoltaic field of the same type and size at a certain time of year. Please provide more details on the analysis:

☐ Difference in the amount and diversity of pollinators (wild bees), between the agrivoltaics field and a non-agrivoltaic field of the same type and size at a certain time of year. Please provide more details on the analysis:

☐ Difference in the presence of butterflies or other insects, between the agrivoltaics field and a non-agrivoltaic field of the same type and size at a certain time of year. Please provide more details on the analysis:

☐ Difference in the presence of birds, between the agrivoltaics field and a non-agrivoltaic field of the same type and size at a certain time of year. Please provide more details on the analysis:

☐Other, please specify:

Agricultural quality testing

57.
Was the quality of the crops under the PV modules tested during the **design phase** of the agrivoltaic field?

☐ Do not know

☐ No, since the purpose of this agrivoltaic field is experimental

☐ A test on a smaller area was performed before building the agrivoltaic system on a bigger area

☐ The agrivoltaic system was designed based on another experimental research. Please specify:

☐ No, the crop quality was not tested before building the agrivoltaics system

☐ Other, please specify:

58.
Is the agricultural quality under the PV system **measured periodically**?
Multiple answers are allowed.
☐ Do not know
☐ No
☐ Yes, the tests are performed periodically in collaboration with research/ university centers
☐ Yes, a small area of the land is dedicated to regular testing of the agricultural quality
☐ Other, please specify:

Crop yield

59.
Please provide information to evaluate the crop variation and yield:

1. Annual crop yield of fruit or vegetables per unit area of the agrivoltaic field (e.g., X kg fruit/ hectare in2024)

2. Annual crop yield of fruit or vegetables per unit of traditional field, without agrivoltaic system (e.g., X kg fruit/hectare in 2024). If the value is not measured directly but taken from literature, please specify the source

Plant phenology

60.
Please, select the options that apply to your agrivoltaic field in relation to its **plant phenology**.
Multiple answers are allowed.
☐ The average vigour in terms of **plant/ sprout height**[3] of the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ The average vigour in terms of **plant diameter** of the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ The average **number of fruits (or pods) per plant** for the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ The average measurement of **photosynthetically active radiation (PAR)** [W/m2] for the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide more details on the measurement methods and results:

☐ Other, please specify:

[3] The height of the plant is measured for horticulture e fields, and length of the shoots for tree fields.

Post-harvest quality

61.
Please, select the options that apply to your agrivoltaic field in relation to the **post-harvest quality of the crops**. Multiple answers are allowed.

☐ The average **fruit/ vegetable diameter** of the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ The average **fruit/ vegetable weight** of the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ The average **sugar content** [brix] of the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ The average **acidity** [pH] of the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ The average **external appearance** [colour, sunburn, russeting etc.] of the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ Other, please specify:

62.
To what extent does the harvest of the agrivoltaic area meet the same **market standard** of the harvest of a non-agrivoltaic field?

☐ Do not know

☐ All the products under the agrivoltaics field meet the same market standard of a non-agrivoltaic field of the same type

☐ Some of the products under the agrivoltaic field do not meet the same market standard of a non-agrivoltaic field of the same type, and they have to be sold in a lower-quality category. Please estimate the amount of these sub standards products (e.g., half of the annual harvest)

☐ Other, please specify:

63.
Are there measurements to **protect crop quality** (e.g., semi-transparent modules, irrigation with water sensors, PV systems integrated with anti-hail nets) in place or are they in program?

☐ Do not know

☐ No

☐ In program1. Please specify the type of measurement and its timeline:

☐ Yes, please specify:

Product certification

64.
Is the agricultural **product certified** with a label that aims to preserve the soil fertility and product quality, or is this activity in program? (e.g., organic, biodynamic, integrated, slow food).

☐ Do not know

☐ No

☐ In program1. Please specify the type of certification and its timeline:

☐ Yes, please specify the type of certification:

☐ Other, please specify:

Soil preservation

65.
Please, select the options that apply to your agrivoltaic field in relation to **soil quality**.
Multiple answers are allowed.

☐ The average **soil pH level** for the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ The average **soil temperature [°C]** for the crops under the agrivoltaics system is different to that of a non-agrivoltaic system. Please provide details on the measurement methods and results:

☐ Other, please specify:

Machinery

66.
Only for open-ground fields.
Is **electric machinery** in use in the agrivoltaics field?
☐ Do not know
☐ No
☐ Yes, some electric machinery is used
☐ Yes, only electric machinery is used

67.
Only for open-ground fields.
Is the agrivoltaics field related to longer hours **of electric machinery?**
☐ Do not know
☐ No
☐ Yes, please specify how:

☐ Other, please specify:

ANNEX II – KPIs tables for scoring method

A2.1. Social KPIs

Table 4 Description of the selected social KPIs and scoring method

QUESTION #	SUBCATEGORY	NAME	DESCRIPTION	SCORING METHOD	RELATED SDG #
13	Diversity and gender equality	Gender equality rate among workers	Gender distribution among AgriPV workers (people who are directly operating in the agriPV field - e.g., owners, farmers, other employees)	Do not know = 0 between 40-60 % balance = 3 Between 20-40% balance = 2 Between 0-20% balance = 1	5
14		Gender equality plans	Are there written measurments in place to improve the gender gap of the workers in the AgriPV plant (e.g., is there a gender equality plan,or/and a transparent declaration of the gender data)?	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	5
15	Health and safety	Health and safety policies and practices in place	Are there written plans of action in place regarding health and safety measurements, including detailing risk assessments, hazard analysis, and measures to prevent workplace-related injuries or illnesses? Other than the mandatory compliance with the EU Directive 89/391/CEE (in Europe) - "testo unico salute e sicurezza sul lavoro" D.Lgs 81/08 and art 21 del D.Lgs 81/08 in Italy.	Do not know = 0 No = 0 Compliant with local legislation = 1 More than legislation (In programme) = 2 More than legislation (in place) = 3	8

16	Fair working conditions	Fair labour policies and practices in place	Are there written plans of action in place regarding fair treatment for workers involved in the AgriPV plant (e.g., plans including written code of conduct against illegal labour, plans including fair wages, fair working hours, equal opportunity for all workers, freedom of association, health insurance guaranteed)?	Do not know = 0 No = 0 Compliant with local legislation = 1 More than legislation (In programme) = 2 More than legislation (in place) = 3	8
17	Suppliers social responsability	Social screening of suppliers	Are the agricultural suppliers (e.g., suppliers of seeds, fertilizers, machinery, agricultural equipment, etc.) checked in terms of social responsibility?	Do not know = 0 No = 0 Yes, suppliers showing attention to the topic of social sustainability are accepted with priority =1.5 Yes, only suppliers showing attention to the topic of social sustainability are accepted = 3	12
18-23	Stakeholder engagement	*See STAKEHOLDER MATRIX TABLE ANNEX table*	*See STAKEHOLDER MATRIX TABLE ANNEX table*	do not know = 0 no stakeholder engagement = 0 stakeholder engagement in program = 0.75 passive stakeholder engagement only = 1.5 active stakeholder engagement only = 1.5 passive and active stakeholder engagement - but opinion collected was not taken into account in the design phase = 2.25 passive and active stakeholder engagement - and opinion was taken into account into the design phase = 3	11
18-23		Number of stakeholder categories involved	How many stakeholder categories were involved	do not know = 0 no stakeholder engagement = 0 stakeholder engagement in program = 1 < 3 stakeholder categories engaged = 2 > 3 stakeholder categories engaged = 3	11
24	Product certification	Certification/label the organization obtained for the product	Does the organization have any social responsibility-related certification/label for the agricultural product produced (e.g., fair trade)?	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	12

25	Energy community	Involvement in energy community	Is the agrivoltaic field part of an energy community?	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	11
26	Communication and transparency	In place communicatio n and/or trainings on gender equality	If the gender equality plan is available, is it transparently communicated inside and outside the organization, or/and are there internal trainings on the topic?	Do not know/No gender equality plan= 0 No = 0 In programme = 1.5 Yes, there is a transparent comunication of gender data and/or training for the employees on the topic = 3	5
27		In place communicatio n and/or trainings on human rights	If a code of conduct regarding human rights of workers is available, is it transparently communicated inside and outside the organization, or/and are there internal trainings on the topic?	Do not know/No human right protection policy= 0 No = 0 In programme = 1.5 Yes, there is a transparent comunication of human rights protection declaration and/or training for the employees on the topic = 3	8
28		In place communicatio n and/or trainings on social responsibility	If social responsibility is measured (e.g., by means of a certification) is it transparently communicated and/or are there internal trainings on the topic, outside the organization?	Do not know= 0 No = 0 In programme = 1.5 Yes = 3	12

Table 5 Stakeholder engagement impact category, evaluation matrix with associated scoring method

STAKEHOLDER NUMBER	STAKEHOLDER CATEGORY	SCORING METHOD	RELATED SDG
1	Farmers - involved in the Agri-PV field	do not know = 0 no stakeholder engagement = 0 stakeholder engagement in program = 0.75 passive stakeholder engagement only = 1.5 active stakeholder engagement only = 1.5 passive and active stakeholder engagement - but opinion collected was not taken into account in the design phase = 2.25 passive and active stakeholder engagement - and opinion was taken into account into the design phase = 3	11
2	Farmers - others than the ones involved in the Agri-PV field	do not know = 0 no stakeholder engagement = 0 stakeholder engagement in program = 0.75 passive stakeholder engagement only = 1.5 active stakeholder engagement only = 1.5 passive and active stakeholder engagement - but opinion collected was not taken into account in the design phase = 2.25 passive and active stakeholder engagement - and opinion was taken into account into the design phase = 3	11
3	Citizens	do not know = 0 no stakeholder engagement = 0 stakeholder engagement in program = 0.75 passive stakeholder engagement only = 1.5 active stakeholder engagement only = 1.5 passive and active stakeholder engagement - but opinion collected was not taken into account in the design phase = 2.25 passive and active stakeholder engagement - and opinion was taken into account into the design phase = 3	11
4	Local community	do not know = 0 no stakeholder engagement = 0 stakeholder engagement in program = 0.75 passive stakeholder engagement only = 1.5 active stakeholder engagement only = 1.5 passive and active stakeholder engagement - but opinion collected was not taken into account in the design phase = 2.25 passive and active stakeholder engagement - and opinion was taken into account into the design phase = 3	11
5	Local authorities	do not know = 0 no stakeholder engagement = 0 stakeholder engagement in program = 0.75 passive stakeholder engagement only = 1.5 active stakeholder engagement only = 1.5 passive and active stakeholder engagement - but opinion collected was not taken into account in the design phase = 2.25 passive and active stakeholder engagement - and opinion was taken into account into the design phase = 3	11

6	Insert Eventual Others	do not know = 0 no stakeholder engagement = 0 stakeholder engagement in program = 0.75 passive stakeholder engagement only = 1.5 active stakeholder engagement only = 1.5 passive and active stakeholder engagement - but opinion collected was not taken into account in the design phase = 2.25 passive and active stakeholder engagement - and opinion was taken into account into the design phase = 3	11

A2.2 Photovoltaics KPIs

Table 6 Description of the selected photovoltaic KPIs and scoring method

ASSOCIATED QUESTION #	SUBCATEGORY	NAME	DESCRIPTION	SCORING METHOD	RELATED SDG #
29	Material supply	Material sourcing - PV cells and wafers	Are the PV cells and wafers manufactured locally (Europe)?	Do not know = 0 No = 0 Yes = 3	12
30		Material sourcing - PV module	Are the PV modules manufactured locally (Europe)?	Do not know = 0 No = 0 Yes = 3	12
31		Material sourcing - BOS	Are the Balance of System (BOS) - supporting components and auxiliary systems (e.g., mounting structures, trackers, inverter) - manufactured locally (Europe)?	Do not know = 0 No = 0 Yes = 3	12
32	Environmental screening of suppliers	Environmental screening - PV modules	Are the PV modules' suppliers checked in terms of environmental sustainability? (E.g., are they required to have an environmental certification/ label?)	Do not know = 0 No = 0 In program = 1.5 Yes = 3	12
33		Environmental screening - BOS	Are the suppliers of PV BOS components (e.g., inverters, mounting structure, trackers, batteries) checked in terms of environmental sustainability? (E.g., are they required to have an environmental certification/ label?)	Do not know = 0 No = 0 In program = 1.5 Yes = 3	12
34	Circularity and Eco-design	Reuse of PV-modules	At the end of its lifetime, are the PV module tested to be reused in the PV second-hand market?	Do not know = 0 No = 0 In program = 1.5 Yes = 3	12
35		Recycled input materials used - PV - weight indicator	Are recycled materials used to produce the PV modules used in the AgriPV system?	Do not know = 0 No = 0 Yes, recycled aluminium is used = +1 Yes, recycled glass is used = +1 Yes, recycled materials are used in the PV cells =+1 (max 3 points)	12

36	End-of-life	End-of-life management plan - PV	Are you informed about the end of life of the PV modules installed in the agrivoltaics field?	Do not know = 0 Yes, generic electronic waste or other type of waste = 1.5 Yes, recycling centre specific for PV waste = 3	12
37		Recycled waste - PV module	Which of the PV modules components will be recycled at the end of its life (e.g., aluminium frame, glass, cables, etc)?	Do not know = 0 None = 0 copper =+ 1 Aluminium = +1 Glass = +1 Silicon = +1 (max 4)	12
38		Recycled waste - BOS	Are you informed about the end of life of the Balance of System (BOS) components installed in the agrivoltaics field? BOS components are: inverters, mounting structure, trackers, batteries, other auxiliary equipment in addition to the PV module.	Do not know = 0 None = 0 Yes, the BOS components at the end of their life will be collected following the directive dedicated to the specific component, but I have no information on the materials that will be recycled =1.5 Yes, the BOS components at the end of their life will follow other routes = 1.5 Yes, the BOS components at the end of their life will be sent to a specific recycling centre =3	12
39	Electric efficiency	PV module efficiency	Which is the PV module efficiency in STC (Standard Testing Conditions) expressed in kWp/m2 of PV module.	Do not know = 0 less than benchmark = 1 as the benchmark = 2 more than benchmark = 3 benchmark = 17%	7
40		PV electricity coverage	Share of energy required by the farm (e.g., light, irrigation, charging of electric machines) that is covered by PV electricity in kWh/year	Do not know = 0 <10% = 1 10-20 %= 2 >30 %= 3	7
41		Tracking system optimization	Are there optimized tracking algorithms in place (i.e. trackers) to maximize energy production?	Do not know = 0 No = 0 Yes = 3	7
42		PV module temperature	Is there a benefit measured in terms of decrease of PV surface temperature in the agrivoltaic field, compared to a traditional PV system installed in the same location, due to the synergy	Do not know = 0 No, the PV surface temperature is measured, but no benefits results from the measurements =1.5 Yes, there is a benefit in	7

			between the crop and the PV system?	temperature thanks to the synergy between crops and PV = 3	
43	GHG emissions	GHG emissions for PV modules production	Kilograms of CO2-Equivalents emitted during the PV modules production step, for a defined funcitonal unit (1 kWp of PV installed)	Do not know = 0 more than benchmark = 1 as benchmark = 2 less than benchmark = 3 benchmark = 600 kgCO2/kWp	13
44		GHG emissions for BOS production	Kilograms of CO2-Equivalents emitted during the Balance of System (BOS) production, for a defined funcitonal unit (defined depending on the type of BOS)	Do not know = 0 more than benchmark = 1 as benchmark = 2 less than benchmark = 3 benchmark for mounting structure, electronics and cabling (no battery) = 295kgCO2/kWp	13
45	Landscape integration	Landscape integration impact	What is the perception of the local stakeholders regarding the visive impact of the agrivoltaics field (e.g., neigh borough farmers, shops, citizens?	Do not know = 0 No, visive impact is not measured = 0 Visive impact is measured, but negative perception resulted = 1 Visive impact is measured, with neutral perception = 2 Visive impact is measured, with positive perception =3	15
46		Landscape integration measurments	Are there measurments in place to better integrate the AgriPV system in its ladscape (e.g., semi-transparent PV modules, colour PV modules)?	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	9
47	General	Communication on the environmental sustainability - inside the organization	Are the policies regarding environmental sustainability measurements transparently communicated, and/or are there internal trainings on the topic, internally to the agrivoltaics organization? (e.g., annual reports, monthly internal meetings, internal courses, etc.)	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	13
48		Communication on environmental sustainability - outside the organization	Are the policies regarding environmental sustainability measurements transparently communicated and/or are there internal trainings on the topic, outside the agrivoltaics organization? (e.g., annual reports,	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	13

			monthly workshops, webinars, social media, etc.)		

A2.3. Agricultural KPIs

Table 7 Description of the selected agricultural KPIs and scoring method

ASSOCIATED QUESTION #	SUBCATEGORY	NAME	DESCRIPTION	SCORING METHOD	RELATED SDG #
49	End-of-life - Agriculture	End-of-life management plan - Agricultural field	Is there a sustainable restoration plan in place for the AgriPV field at the end of its lifetime?	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	12
50		Valorization of agricultural waste	Is there an energetic valorisation of agricultural waste (e.g., annual pruning) practices in place?	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	12
51	Water	Water efficiency	Is there a decrease in water need in the agrivoltaic field (agricultural consumption of irrigation water only), compared to the reference demand of control area without agrivoltaic?	Do not know = 0 No, the water needed by the crop under the agrivoltaic modules is higher = 0 No, the water needed by the crop under the agrivoltaic modules is the same = 1.5 Yes, there is a decrease in the water needed by the crop under the agrivoltaic modules = 3	6
52		Water resource optimization	Are there rainwater recovery systems in place?	Do not know = 0 No = 0 In programme = 1.5 Yes = 3	6
53	Land use	Land Area Occupation Ratio (LAOR)	What is the ratio between the area occupied by PV system (Spv) and the total area of the agrivoltaic system (Stot)? Definitions: Spv = sum of the surfaces identified by the external profile of maximum size of all the PV modules constituting the system (active area including frame) Stot = area which includes the area used for crop and/or livestock farming	Do not know = 0 >40% = 0 30-40% = 1.5 <30% = 3 * in accordance with Italian document "Linee guida Impianti agrivoltaici 2022"	15

			and the total area on which the agri-voltaic plant stands		
54		Land conservation	What was the type of land before the installation of the Agri-PV field?	Do not know = 0 Uncoltivated land = 1.5 Agricultural field = 3 Photovoltaic field = 3	15
55	Biodiversity	Agrobiodiversity	Is the agrobiodiversity taken into account in the agrivoltaics field (e.g., certification/ label, use of different agricultural species are cultivated, periodic rotation of culture is applied to preserve soil quality, use of companion plants)?	Do not know = 0 No = 0 In program = 1.5 Yes = 3	15
56		Preservation and increase of biodiversity (only for open ground fields)	Are there measurement to preserve and increase the biodiversity in the agrivoltaics field (e.g., non-cultivated areas, hedges, small ponds and rows of trees to increase the presence of pollinators and maintain the landscape)?	Do not know = 0 No = 0 In program = 1.5 Yes = 3	15
57		Quantification of biodiversity (only for open ground fields)	Are there in place measurements to quantify the biodiversity of the agrivoltaic field?	Do not know = 0 No = 0 In program = 1.5 Yes = 3	15
57		Measurement of biodiversity (only for open ground fields)	Which biodiversity measurements are quantified?	Do not know = 0 Amount and diversity of flowering= +1 Amount and diversity of pollinators (wild bees) = +1 Presence of butterflies = +1 Presence of birds = +1 Others = +1 (max 5 points)	15
58	Testing	Agricultural quality testing - design phase (only for non-experimental agrivoltaic fields)	Was the quality of the crops under the PV modules tested during the design phase of the agivoltaic field?	Do not know = 0 No test = 0 The agrivoltaic system was designed based on other experimental research = 1.5 Test based on literature = 3	15

59		.Agricultural quality testing - operative phase	Is the agricultural quality under the PV system periodically measured?	Do not know = 0 No test = 0 Yes, the tests are performed periodically in collaboration with research/ university centres = 1.5 Yes, A a small area of the land is constantly dedicated to the test of the agricultural quality = 3	15
60	Crop quality	Crop yield variation	Crop yield variation in comparison with a non-agrivoltaic field?	Do not know = 0 Agricultural crop yield reduction in comparison with a control area >60 % = 1 Agricultural crop yield reduction in comparison with a control area between 0-60% = 2 Agricultural crop yield reduction in comparison with a control area <20% = 3 Agricultural crop yield increase in comparison with a control area = 3	15
61		Plant phenology - Plant vigor - Plant/ sprout height	Is there a difference between average height of the plant (for horticulture)/ length of shoots (for trees) in a control area, and in an agrivoltaic field?	Do not know = 0 Reduction >60 % = 1 reduction 40-60% = 2 Reduction <20% = 3 Increase in comparison with a control area = 3	15
61		Plant phenology - Plant vigor - Diameter	Is there a difference between the average diameter of the plant in a control area, and in an Agri-PV area of the same size, at collection time?	Do not know = 0 Reduction >60 % = 1 reduction 40-60% = 2 Reduction <20% = 3 Increase in comparison with a control area = 3	15
61		Plant phenology-Number of fruits (or pods) per plant	Is there a difference between the average number of the fruits/ vegetables/ pods per plant in a control area, and in an Agri-PV area of the same size, at collection time?	Do not know = 0 Reduction >60 % = 1 reduction 40-60% = 2 Reduction <20% = 3 Increase in comparison with a control area = 3	15
61		Plant phenology - Photosynthetically active radiation (PAR)	Is there a difference between the (Photosynthetically active radiation) - in W/m2 - in a control area, and in an Agri-PV area of the same size, at collection time?	Do not know = 0 Reduction >60 % = 1 reduction 40-60% = 2 Reduction <20% = 3	15

62		Postharvest Quality traits - Average fruit/ vegetable diameter	Is there a difference between average diameter of the fruit/ vegetable in a control area, and in an Agri-PV area of the same size, at collection time?	Do not know = 0 Reduction >60 % = 1 reduction 40-60% = 2 Reduction <20% = 3	15
62		Postharvest Quality traits - Average fruit/ vegetable weight	Is there a difference between average weight of the fruit/ vegetable in a control area, and in an Agri-PV area of the same size, at collection time?	Do not know = 0 Reduction >60 % = 1 reduction 40-60% = 2 Reduction <20% = 3	15
62		Postharvest Quality traits - Sugar content	Is there a difference between average sugar content - in Brix - of the fruit/ vegetable in a control area, and in an Agri-PV area of the same size, at collection time?	Do not know = 0 Reduction >60 % = 1 reduction 40-60% = 2 Reduction <20% = 3	15
62		Postharvest Quality traits - Acidity	Is there a difference between average acidity level - pH - of the fruit/ vegetable in a control area, and in an Agri-PV area of the same size, at collection time?	Do not know = 0 Reduction >60 % = 1 reduction 40-60% = 2 Reduction <20% = 3	15
62		Postharvest Quality traits - External appearance	Is there a difference of color, sunburn, russetting etc. between fruit/vegetable in a control area, and in an Agri-PV area of the same size, at collection time?	Do not know = 0 Strog worsening = 0 Small worsening = 1.5 No difference = 3 Improvement = 3	15
63		Postharvest Quality traits - Market standard fit check	To what extent does the harvest of the agrivoltaic area fit in the same market standard of the harvest of a non-agrivoltaic field?	Do not know = 0 Agrivoltaic products fit under a lower category = 1.5 Same market standard = 3 Higher market standard = 3	15
64		Crop quality protection measurement	Are there measurements in place to protect crop quality (e.g., semi-transparent modules, irrigation with sensors, PV systems integrated with anti-hail nets)?	Do not know = 0 No = 0 In program = 1.5 Yes = 3	15
65		Product certification	Is the agricultural product certified with a label that aims to preserve the soil fertility and product quality? (e.g., organic, biodynamic, integrated, slow food).	Do not know = 0 No = 0 In program = 1.5 Yes = 3	12

66	Soil improvement and preservation (only for open fields)	Soil PH	Is there a difference between average acidity level of the soil in a control area, and in an Agri-PV area?	Do not know = 0 Difference >60 % = 1 Difference 40-60% = 2 Difference <20% = 3	15
66		Soil temperature	Is there a difference between average temperature of the soil in a control area, and in an Agri-PV area?	Do not know = 0 Difference >60 % = 1 Difference 40-60% = 2 Difference <20% = 3	15
67	Machinery	Agricultural machinery use (only for open fields)	Difference between hours of machinery required in a control area, to harvest a certain quantity of biomass, and an Agri-PV area of the same size, in a certain time frame (year)?	Do not know = 0 Yes, the presence of PV systems in the field is complicating the machinery operations, causing more machinery hours than a normal non-agrivoltaic field =1.5 No, the presence of PV system in the field is not affecting the machinery operations = 3	15
68		Types of machines (only for open fields)	Which type of machinery is used in the agrivoltaic field?	Do not know = 0 Only fossil fuel machinery = 0 Some electric machinery in use = 3	15

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