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Value4Farm

VALUE4FARM

D1.1 Report on farmers' needs and decision support tool

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DATA	Data sets, microdata, etc.	
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LIST OF ABBREVIATIONS

AU	Aarhus Universitet
CIB	Consorzio Italiano Biogas E Gassificazione
DSS	Decision Support System
DST	Decision Support Tool
EO	Earth Observation
GHG	Greenhouse Gasses
GIS	Geographic Information System
INA	Inagro, Provinciaal Extern Verzelfstandigd Agentschap In Privaatrechtelijke Vorm VZW
IUNG	Instytut Uprawy Nawozenia I Gleboznawstwa, Panstwowy Instytut Badawczy
LO	Learning Objective
OKD	Orkidea
OOC	Open Online Course
REM	REM Tec Srl
UCSC	University Cattolica del Sacro Cuore
UREAD	University of Reading

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KEYWORDS LIST

- Farmer Needs
- Decision Support Tools
- On-Farm Energy
- Anaerobic Digestion
- Agrivoltaics

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EXECUTIVE SUMMARY

Value4Farm (V4F) has the overall objective of demonstrating the effectiveness, sustainability and replicability of renewable-based value chains that integrate sustainable food production and renewable energy generation. It is clear that for progress to be made toward achieving this objective that farmers, farm managers and a range of stakeholders need to be involved from the start of the project and throughout to ensure the project can fully understand their needs, challenges and concerns related to integrated food and energy production, and so that these views can guide the success of the V4F project. In this context UREAD co-ordinated WP1 and specifically two of its tasks, T1.1 the collection of farmer needs to help inform the modification of crop protocols and the setting up of demonstration sites and, T1.4 the provision of a framework of a decision-support tool (DST) which allows farmers to explore the adoption of integrated food and energy production on their farms. The key messages for V4F project going forward are:

To consider if there are mechanisms that allow the farmer to "trial" adoption on smaller areas to demonstrate success and then to gradually scale over time. This is related to the context of whether the "system boundary" in terms of food/energy sustainability is viewed at the individual farm level which may be appropriate on some farms/regions, or whether the boundary relates to a number of farms in an area working in co-operation.

To be aware that the protocols and technologies being proposed will generally require a change to a given on-farm system, an investment in new technology, will require knowledge acquisition on behalf of the farmer and may, at least initially make their farm management operations more complicated. It is thus key that the project not only demonstrates improved environmental sustainability but that realistic and transparent financial cost modelling in relation to adoption can demonstrate a [substantial] financial benefit to a given farm business.

To ensure differing rotational suggestions are as flexible as possible and as closely aligned with existing knowledge in a given region. Introducing completely novel crops and rotations in addition to the expectation of the farmer to adopt new energy technology will heighten the adoption barrier.

The importance of the demonstration and replication sites that are being established is clear and thought is needed to ensure as many farmers as possible are exposed to these. In person exposure is most preferable to end-users, but careful thought is needed about how a wider audience can be reached on a regular basis to "see" and experience the demo sites in operation, but also to ask questions in the context of operation of their own farming systems particularly in relation to set up issues/costs and crop protocols.

The development of the DSTs will need to start from the two key declared motivations for this investment: improving farm profits and improving the sustainability of the business.

In relation to the demonstration and replication sites, the DSTs will need to incorporate access to, videos from and data related to these practical, on-site knowledge exchange experiences and provide interactive elements within a holistic and evidence-based educational package.

1. FARMERS' NEEDS AND DECISION SUPPORT TOOL FRAMEWORK

1.1 Background and creation of the farmers' network

UREAD was responsible for the coordination of the creation of the farmers' network. Each demonstration site (INA, AU, UCSC, REM, CIB) and replication site (CIB, IUNG, OKD) identified a network of farmers to contact in order to better understand and map their needs in terms of crop, energy demand etc. through a bottom-up approach. UREAD designed a survey for farmers that each partner sent to its network once the survey was translated into the local language. A round of consultations and in-person meetings with a small number of farmers and stakeholders in the form of a focus group discussion were used to develop and order the end-user needs, as well as to structure a set of user stories to support the development of the decision support tool. These results will be used to inform T2.2 for the development of the agricultural protocols. A review of the literature was undertaken on the existing protocols in order to identify the gaps in existing practices and to identify the factors affecting the adoption of protocols by farmers.

1.2 Importance of understanding and mapping farmers' needs

Understanding and mapping farmers needs and involving farmers in the development of systems and processes that aim to support their farming activities can increase their relevance, usefulness, uptake and use. Thus involving farmers and end-users from the start of the Value4Farm project via demonstrations, workshops and advisory meetings will inform the design of the cropping protocols, the nature of energy demonstration that would be most useful to end-users and ensure that the DST produced as part of the project is designed specifically with stakeholder end use at its core. Rose et al., (2016) developed a checklist for agricultural DSTs to encourage uptake by farmers, the list includes: Ease of use; Trust (is the tool evidence based and do users trust it?); Habit (does the tool fit with the farmer's existing habits?) and; relevance to user.

The process of understanding and mapping farmers needs can also bring in expertise and knowledge (Kenny et al., 2021) and gives a wider understanding of the challenges faced, enabling, for example, processes, policy and systems to better respond to the issues experienced by farmers.

The Value4Farm project will consider and respond to farmers needs throughout the project via numerous demonstration activities conducted at our demonstration facilities and also through an advisory board.

1.3 Objectives

The main objectives of these elements of WP1 were to:

- Coordinate the creation of a farmer network
- Review the literature on aspects of integrated energy and food production, cropping rotations and protocols and the use of DSTs on farms

- Design a questionnaire and focus group questions to explore farmers' knowledge needs
- Develop list of user stories and identify end-user needs
    - To inform the Decision Support Tool (T1.4 & 4.5)
    - To inform the 3 agricultural protocols (T2.2)
        - Sustainable agricultural crop protocol for the Atlantic pedoclimatic region
        - Sustainable agricultural crop protocol for the Mediterranean pedoclimatic region
        - Protocol of good practices for handling already existing residual crop streams and usage of digestate

1.4 Literature review of cropping protocols and Decision Support Tools (Task 1.1)

The full review is presented in Appendix 1. Here only a short summary with the key points identified from the literature is presented.

Across the European Union (EU) agriculture and forestry accounted for 3.2% of direct energy consumption in 2020, the majority (56%) of this was from oil and petroleum products. Between 2000 and 2020 the direct consumption of energy in the EU from renewables and biofuels more than doubled, a pattern followed in the agricultural and forestry sector with approximately 11% of the energy consumed in 2020 coming from renewable or biofuel sources (Eurostat Energy Use, 2022). Energy is used in wide range of settings, from diesel consumption in farm machinery to the electricity used to power greenhouses and irrigation systems (Paris et al., 2022) and energy for these systems could come from a variety of sources, including heat pumps, natural gas, wind turbines, solar panels, fossil fuels, biomass and biogas.

This review explores the current use and potential use of energy generation in agricultural settings across Europe and the benefits and barriers to growing energy crops and producing energy. It will also consider the information and knowledge sharing available to farmers to help them explore the opportunities to generate energy and how this may benefit their farm, in particular the decision support tools and systems available to farmers to help them explore and monitor crops growing and energy use and production on their farm.

1.4.1 Crops – Food, Feed and Energy

Across the European Union (EU) a diverse range of crops are grown commercially. Crop production is focussed on arable crops, predominantly cereals (such as wheat, barley and oats), with root crops and oilseeds also making up a large proportion of crop production (Eurostat crops, 2022). In 2020 approximately 157 million hectares of land in the EU was used for agricultural production, arable land accounted for 62% of agricultural land use. Of the crops grown on arable land, cereals occupied 54%, fodder crops 21%, and industrial and other crops (including biofuels) around 25% (Eurostat cropping patterns, 2023). The majority of cereal crops grown in the EU are for human consumption or livestock feed / fodder provision, see figure 1.

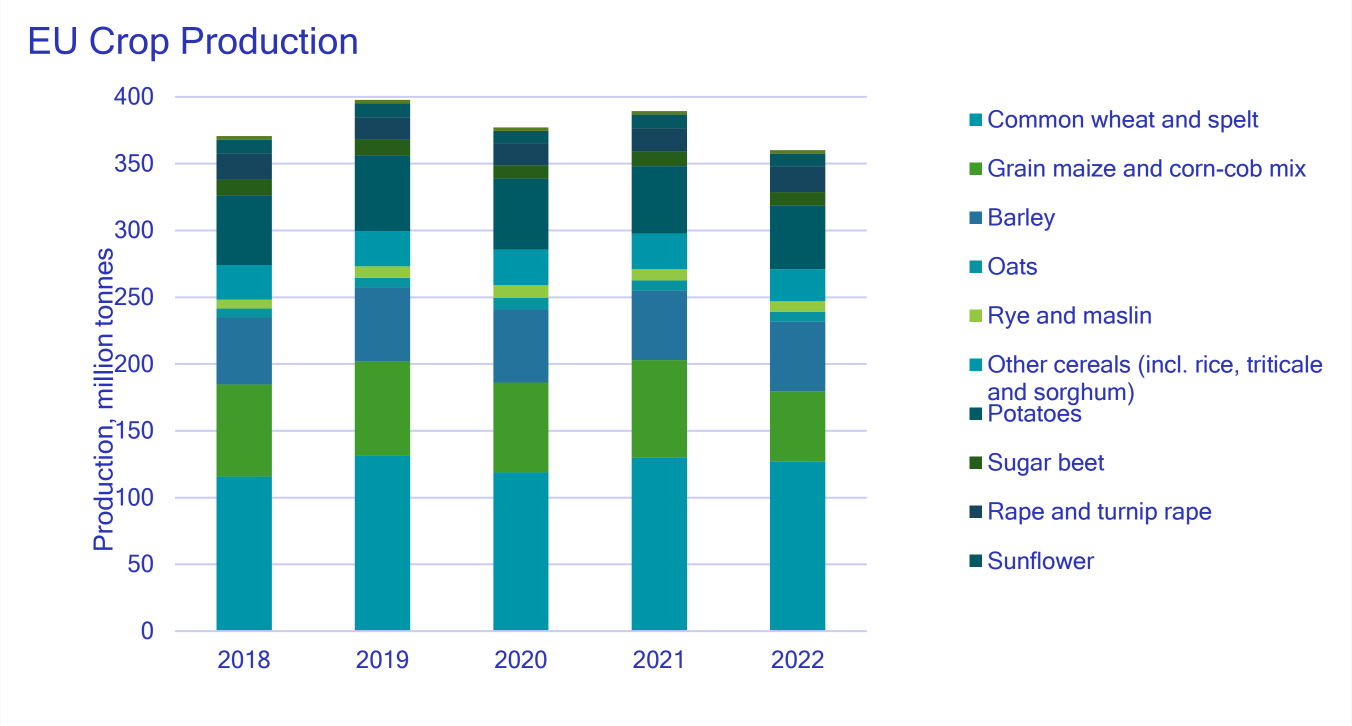


Figure 1: Breakdown of main cereal, root crop and oilseed crop production (million tonnes) from 2018 – 2022 in the EU. 2018 – 19 EU28, 2020 – 22 EU27 (following the UK leaving the EU). Data from Eurostat database (2023)

1.4.2 Energy crops and bi-products

The crops grown to generate biofuels can be wide-ranging, for example oilseed crops producing the precursors for biodiesel production, starch and sugar crops produce the material for bioethanol production and grasses and short rotation coppice for the production of biomass. There is also the potential for bi-products or waste from food and fodder crops to form an important part of energy generation.

Figure 2 highlights some of the routes for the conversion of biomass to energy, considering both energy crops and the byproducts of food and fodder crops and other agricultural wastes (European Environment Agency, 2013).

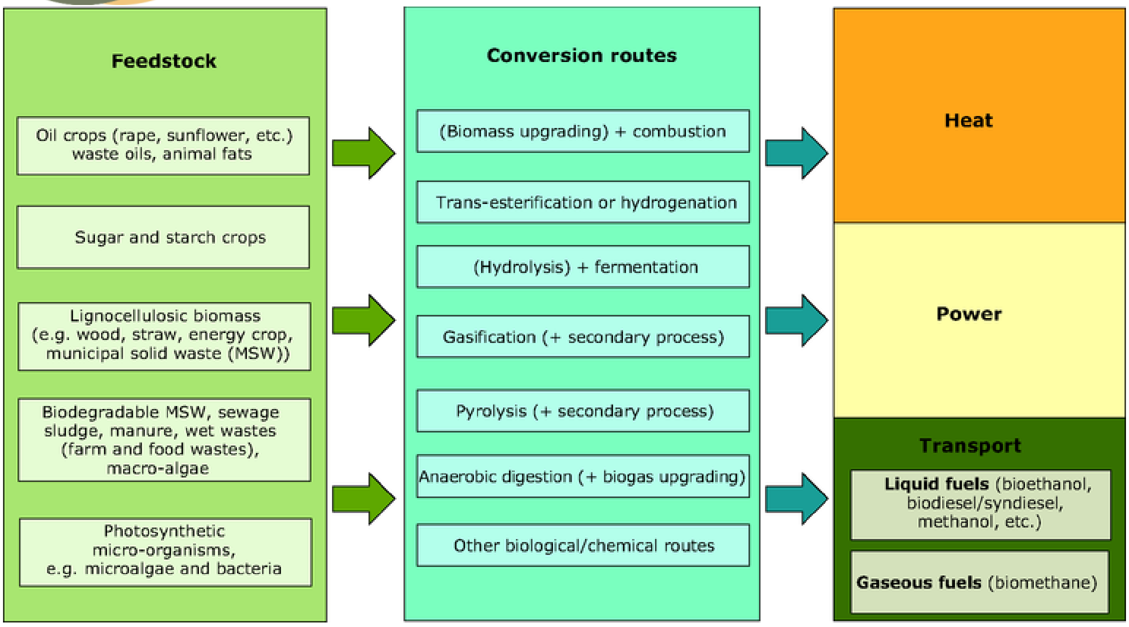


Figure 2: Routes for converting biomass to energy, (European Environment Agency, 2013).

1.4.3 Crop rotations

Crop rotation, the practice of alternating the crops grown in a set sequence so crops of the same species are not generally grown without interruption on the same field, can support a range of agricultural and ecological benefits. Integrated crop rotations can bring together multiple crop types in order to produce food, feed, raw materials and energy, they may also include cover crops which could be used for energy generation.

The literature suggests that the main barriers faced by farmers when considering whether to grow energy crops or include energy crops in their rotations include:

- **Economic factors:** Depending on market prices, energy crops may bring less profit than food or fodder crops
- **Annual vs. perennial energy crops:** Perennial energy crops may require several years before they produce enough biomass to harvest or have an economic benefit, whereas annual energy crops can be included as part of rotations with food and fodder crops.
- **"Not what a farmer does", farmers produce food, not energy:** Social, society and community expectations of what farmers do may have an impact on farmers interest in and willingness to grow dedicated energy crops (Jonsson et al., 2011).
- **Land not appropriate for energy crops:** Topography or soils unsuitable for energy crops or the machinery required for harvesting.
- **Knowledge gaps:** Gaps in farmer's and advisor's knowledge and the research around energy crops and energy crop rotations (Ditzler et al., 2021)

1.4.4: Energy production - Agrivoltaics and Biogas

Agrivoltaics is the simultaneous use of land for both solar photovoltaic power generation and agriculture. Photovoltaic panels can be mounted at a height from the ground that enables conventional cultivation practices underneath, leading to the potential for more efficient land use, areas can be used to grow crops, house livestock and generate electricity.

The literature suggests that agrivoltaics could have wide-ranging benefits on farms and farming, including:

- Crop shade and shelter **-** reducing evapotranspiration, reducing water use and irrigation needs, and potentially giving farmers the chance to grow alternative crops (Amaducci et al., 2018).
- Additional farm income and / or reducing energy bills on the farm from electricity generation and the potential for additional farm income through “renting” land for agrivoltaics
- The possibility of supplying into a national grid (electricity) network thus providing wider societal benefit as well as direct income

However, a range of challenges were highlighted including:

- Issues related to accessibility for agricultural machinery and equipment (Toledo and Scognamiglio, 2021)
- Soil compaction from installation
- If attempting to connect to the grid the placement and costs associated with physical changes or additions to the electrical networks will be an important consideration
- Social acceptance – from both farmers and the general public is also a key issue in the literature (Torma and Aschemann-Witzel, 2023). NIMBY (Not in My Backyard) has been used to represent social opposition to projects that are perceived to negatively impact the environment and local community.

Through the process of anaerobic digestion organic matter can be converted into biogas, a methane rich gas which can be used to generate heat and electricity. Alternatively, biogas can be upgraded to biomethane and used as, for example, transport fuel. The process also produces digestate, a nutrient rich product, that can be used as a fertilizer (Gaffey et al., 2023)."Anaerobic digestion can use a range of organic matter as feedstock (for example livestock, crop and food waste and dedicated energy crops) to produce energy.” (Dale et al., 2016).

Biogas production can be undertaken at different scales, for example using small farm-based digesters, utilising farm wastes and producing energy for use on or off-farm, or larger municipal digesters taking in feedstock from a wider range of producers (e.g. industrial food waste in addition to farm waste) and producing energy to feed into the national power grid. Large scale digesters could take in a more extensive range of wastes as feedstocks (for example waste originally headed for landfill) and supply more energy to the national electricity grid. However, there will be increased travel distances to get feedstock to the plant, increasing greenhouse gas emissions, and they may face local opposition or issues around planning permission.

1.4.5: Main points raised in the literature

- A holistic view needs to be taken of combining food and energy production on farms. Agrivoltaics enable on-farm electricity generation, however the set-up of photovoltaic panels and the crops grown alongside them needs to be carefully considered to minimise yield reductions from shading or selecting crops that would benefit from shading.
- Biogas generation from dedicated energy crops can enable energy generation on and off-farm and may offer farmers a way of making use of agricultural waste and bi-products and generating additional farm income. This use of waste and the byproducts of farming to generate biogas and energy, rather than dedicated energy crops, ensures productive land can produce food and thus may be more acceptable to many farmers and society generally.
- Financial factors play a substantial role in farmers decision making around combining food and energy production. Perennial energy crops may have a long lead in time before harvest, agrivoltaic systems and anaerobic digesters can be expensive to install and maintain and again, there may be a long lead-in time before farmers see any financial benefit from their investment.
- Adopting agrivoltaics or biogas production needs to take into account the energy use and production across a wide range of variables. For example, having larger centralised municipal digesters means more waste can be utilised, but increases energy use in transporting to the digestor, and crops grown for use in biogas production can require differing fertiliser inputs and have varying levels of methane yield.
- At a local level, adapting crop rotations can provide a way of maintaining food / animal feed production while growing some dedicated energy crops, utilising crop wastes and supporting soil health.
- In terms of the financial implications at farm-level the changing energy and food prices are an important consideration, impacting on farm income and profitability. For example, increasing oil prices could make biofuels from dedicated energy crops more attractive than food crops.
- There are a wide range of environmental considerations in supporting energy production. For example, focussing on crops that require less input, how using agrivoltaics can reduce the need for e.g. irrigation, looking at how having e.g. smaller local biogas plants can reduce transportation.
- There also needs to be consideration of the environment in terms of region, for example, some crops or types of agrivoltaics will be more successful depending on farm “type” and area, different crops and rotations in northern /and southern Europe.
- Pulling together all the information to work out all the “variables” such as changes in crop production, the amount of energy produced by biogas or agrivoltaics, the types of crops to grow or crop waste that can be used, rotations to both support the soil and environment, reduce fertilisers and grow crops for energy production is time consuming, farmers and advisors need access to information and support in order to fully consider and effectively implement changes.
- The review suggests that access to regional demonstration sites will help expose farmers to the possibilities of integrating food and energy production as will the effective use of “champion” farmers who are in the successful vanguard of adopters.
- Such demonstration sites can also illustrate the types of cropping protocols that will enable successful integration of food and energy production, as well as illustrating the “physical” infrastructure required for successful adoption. It is clear that training related to the on-farm possibilities will encourage

adoption, as will more information on the financial aspects of integrating food and energy production. A potential framework for such training is provided later in this document.

2. EVALUATING USER NEEDS FROM SURVEY AND FOCUS GROUP DEPLOYMENT (TASK 1.1)

2.1 Network Recruitment and survey design

2.1.1. Rationale behind recruiting farmers related to the sites for the network

The value chains being developed and applied as part of Value4Farm are designed to suit a multitude of conditions spanning Europe, for example, the wind sheltering being demonstrated at AU can be applied throughout the Northwest of Europe. Existing Farmer Networks in the vicinity of each demonstration and replication site [see figure 3] will be consulted throughout the project to ensure the success of the local demonstration/replication site, and to enable maximum impact from the project. They will also be utilized to identify a core of at least 200 V4F network farmers.

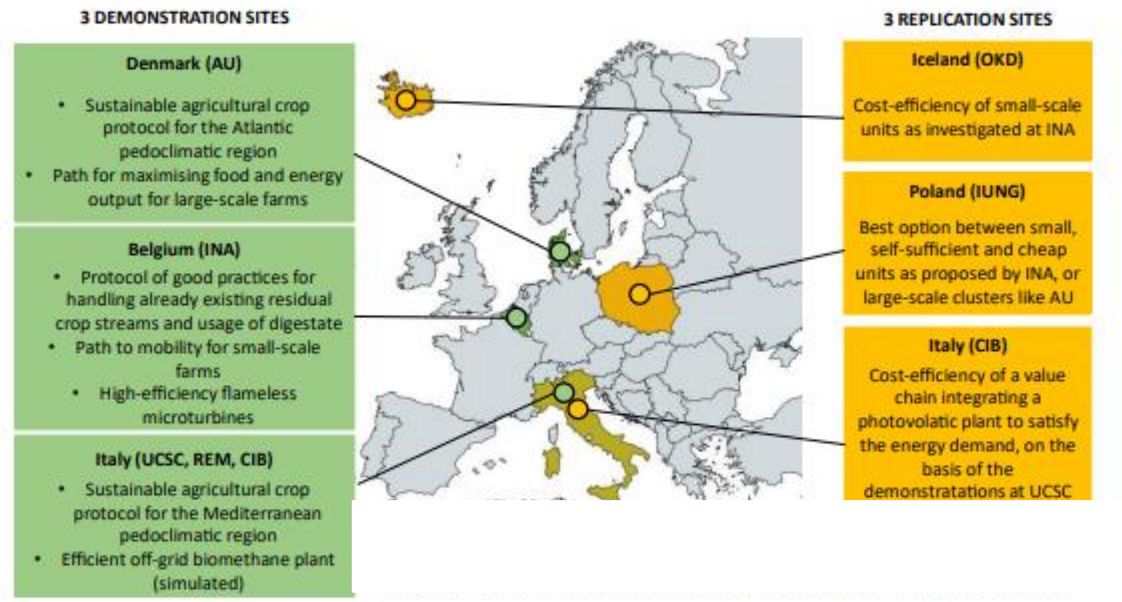


Figure 3: Illustration of the position of demonstration and replication site in the V4F consortia

Each project partner has an established communication network within their local farming community, either through direct contact or indirectly through local farming authorities and organisations. These were utilised as a basis to establish a V4F farmer network and to gather baseline information for the project via a questionnaire.

2.1.2. Outline of the survey and rationale

The farmer survey was designed to collect information on farmers' needs in relation to renewable energy production on farm through the adoption of anaerobic digesters and/or solar panels for electricity generation. In an ideal world, survey design would follow a period of comprehensive literature review and consultation with stakeholders through focus groups or similar. However, in this case, time and resources were not available for such an approach.

As a result, a streamlined procedure had to be used to design a survey instrument to elicit farmer interest in what adoption of a substantial capital investment in a diversified enterprise might entail, and what the drawbacks might be. Thus, in months 1 to 2 of the project, the responsible partner (UREAD) carried out a brief review of the relevant literature. They also drew on their experience with two related projects on introducing biogas on farms (Tranter et al., 2011) and agroforestry on farms (Felton et al., 2023) as well as consulting with other V4F partners to plan a survey and design a draft questionnaire.

This plan was presented to the full project start-up meeting in M2 of the project and subjected to a comprehensive discussion. Following an iterative process with partners, a final version of the survey questionnaire was agreed on in early M3 of the project. It was in two parts, i) questions asked about the farmer/manager and the farm business they run; and ii) questions ascertained whether the range of renewable energy production proposed in V4F would suit their businesses and whether they would consider becoming involved in these forms of integrated food and energy production systems.

UREAD provided 'A1 draft' versions of the questionnaire in English for delivery by the online survey package - Qualtrics. Following the Ethical Clearance procedure being carried out according to UREAD's procedures, translation via the Qualtrics system was carried out and shared with the five different national survey partners. After a period of iterative consultation and back translation by the different teams, a final questionnaire was ready at the end of M3 of the project. This was then made available by UREAD for the survey partners in both a hard copy version for delivery by either hand or post, and via Qualtrics online. Distribution by both methods started at the end of M3 and the beginning of M4.

UREAD has taken steps to enable the receipt of completed questionnaires to be recorded on a database that can readily be interpreted and used for analysis, especially for that involving different partner countries and, also, analysis of non-response bias.

To achieve a representative sample across Europe, project partners were instructed to distribute the survey through the above channels to at least 130 farmers.

In Belgium, Denmark and Iceland the survey was undertaken by an online questionnaire. In Poland the questionnaires were available both online and on paper and, in Italy, paper copies only. In each country, one reminder message was sent to the potential participants.

2.2 Outcomes from primary survey

The survey was dispatched by partners on the 11th November 2023 and concluded on the 31st January 2024 (70 days). Table 1 illustrates that across the five survey countries 4834 questionnaires were distributed resulting in 170 usable responses; this is a response rate of 3.5% which is somewhat low for surveys of farmers (see, for instance, Felton et al., 2023). This can be in part explained by the strict project deadlines which limited the time that the survey could be open, that only one reminder was sent, and that the survey took place in the run-up/over Christmas 2023.

Table 1: The number of questionnaires distributed and responses received by survey country.

	Questionnaires distributed	Responses
Belgium	2506	38
Denmark	420	22
Iceland	850	41
Italy	836	35
Poland	222	34
Total	4834	170

Table 2 shows some key characteristics of the respondents in the five survey countries. Considerable variation between survey countries is apparent for total area farmed and, also, for total number of regular workers. For example, in terms of size the range was from Italy with a mean of 285 ha to Poland with a mean of 29.5 ha. For total number of regular workers, the range was Italy with a mean of 8.39 to Poland with a mean of 1.57.

Table 2: Key respondent characteristics by survey country.

	Mean total area farmed (ha)	Proportion of respondents over 50 years old (%)	Mean total number of regular workers[1]
Belgium	69.7 (SD=166)	64.7	1.69 (SD=1.46)
Denmark	123.0 (SD=242)	90.9	2.76 (SD=5.74)
Iceland	246.0 (SD=317)	73.2	2.13 (SD=1.2)
Italy	285.0 (SD=279)	81.5	8.39 (SD=6.21)
Poland	29.5 (SD=54.7)	44.1	1.57 (SD=1.07)

[1] Including respondent and their family.

The respondents were predominantly over 50 years old with the exception being for Poland where only 44.1% were. For Denmark, some 91% of respondents were over 50 years old, and in Iceland, around 73% were. The respondents comprised of 30 females, 134 males and 6 declined to specify their gender.

As with all surveys, there is a possibility of 'non-response bias' i.e. those who did not respond to the survey may be different in some pertinent way from those who actually did respond. In order to test for this, we examined the characteristics shown in Table 2 for the first and the last tertiles of respondents. This test assumes that those who responded last are more likely to be similar to those who did not respond than those who responded earlier (e.g. MacDonald et al., 2009; and Jones et al., 2015).

No statistically significant difference between the 'early' and 'late' respondents was found in the proportion of farmers over 50 years old (X2 = 0.62, P = 0.431). However, statistically significant differences between the 'early' and 'late' respondents were found for total area farmed (t = 2.7509, P = 0.0076) and total number of farm workers (t = 3.128, P = 0.0032). Thus, there is reason to suppose that respondents who did not respond to the survey are significantly different from those who did in that they are likely to have larger farms and larger work forces.

2.2.1: Contextual information on survey farms and farmers

Of the 170 responding survey farms the mean farm size was 154 ha with a range from 0.1 – 1400 ha.

Table 3 shows the land use pattern on the survey farms by number of farms and mean area per farm. The most common land use on the survey farms was cereal production [71% of the respondents] with a mean area of 75 ha of cereals per farm. The next most common land use was grass leys on 59% of the farms followed by permanent pasture and rough grassland with 48% of the respondents having this land use. The least common form of land use was horticulture under glass practised by 18% of respondents. Such a land use had the smallest mean area on each farm of 0.4 ha.

Table 3: Land use on the survey farms.

	Number of farms with each land use	Mean area on each farm (ha)
Cereals	120	75.3
Other arable crops	88	26.4
Grass leys	101	36.0
Permanent pasture and rough grassland	82	124.0
Horticulture field crops other than roots	43	3.1
Horticulture under glass or plastic	31	0.4
Root crops	40	11.6
Crops grown for biomass energy	66	86.8

The tenurial arrangements on the survey farms are shown in Table 4 by number of farms and mean area per farm. It can be seen that the most common form of tenure was owner-occupation on 76% of the respondents' farms; renting on long-term agreements was the next most common form of land tenure with 33% of the respondents having it. The least common form of land tenure held on the survey farms was share farming which was found on 16% of the respondents' farms.

Table 4: Tenurial arrangements on the survey farms.

	Number of farms with each tenure type	Mean area on each farm (ha)
Owner-occupied	129	157.8
Rented on long-term agreements	56	51.0
Rented on other agreements	29	23.2
Share-farmed	27	43.7

Of those who had owner-occupied areas, the mean area of land under such tenure was 158 ha and, for those who had land rented on long-term arrangements, the mean area held was 51 ha. For the least common tenurial arrangements, share farming, the mean area held per farm was some 44 ha. Further investigation of farm size by country reveals the larger farms are primarily owned in Iceland, Italy and Denmark (table 5). The numbers of different types of livestock on the survey farms is shown in Table 6. The most common type of livestock kept on the survey farms was dairy cattle, kept on 42% of the survey farms; the mean number of dairy cows on such farms was 151. The next most common type was sheep which were found on 31% of the survey farms with a mean headage of 76 per farm.

Table 5: Tenurial arrangements by country

Country	Owner Occupied (Mean area on each farm (ha))	Rented on long-term agreements (Mean area on each farm (ha))	Rented on other-agreements (Mean area on each farm (ha))	Share-farm (Mean area on each farm (ha))
Belgium	20.3 (n=28)	28(n=5)	18.6(n=10)	5 (n = 5)
Denmark	133(n=28)	28 (n= 21)	56.2(n=6)	0 (n=2)
Iceland	284 (n=34)	124(n=15)	20.7 (n=7)	206 (n=4)
Italy	279 (n=26)	80 (n=1)	0	50 (n=6)
Poland	29.9 (n= 25)	9.07 (n=14)	0.8333 (n=6)	3.1 (n=10)

Table 6: Livestock numbers on the survey farms.

	Numbers of farms with each livestock type	Mean numbers on each farm
Dairy cattle	71	151.0
Beef cattle	52	113.7
Sheep	53	74.9
Poultry	37	441.8
Pigs	48	2083.4

A wide variety of miscellaneous livestock was found on the survey farms, these included alpacas, horses, goats, donkeys, rabbits and mink.

Survey farms had, on average, 3.4 full-time workers and 5.9 part-time workers; these farmers included the respondent and their family members. Of those respondents who answered the question, 82% were male and 18% were female and their average age was 54 years old.

Some 34% of the respondents had ‘definitely’ or ‘very likely’ identified a successor and 40% said they were unlikely to have identified one or definitely had not. Respondents suggested that almost 40% of household incomes came from sources other than the farm business. This appears high but in some of the countries surveyed part-time farming alongside another job is not uncommon.

Respondents were asked about the viability of their farm business: 5% said their business was not profitable and may not survive; 18% said their business was not profitable but could survive for at least five years; 28% said their profits were down but their business should be able to survive; 42% said they were maintaining a steady profit level; and 7% were increasing their profit level.

Just over 35% of the respondents belonged to a selling co-operative and 14% to a buying co-operative.

2.2.2: Energy use and production

Of the survey respondents, 96% were on the National Grid for electricity supply, 28% for gas and 52% for heat.

A total of 70 participants indicated that they produced their own energy on their land. Table 7 shows the proportion of the respondents producing their own energy by nine different types. It can be seen that the type of energy that was most commonly produced was Combined Heat and Power by 46% of the respondents, followed by electricity from solar panels on buildings and non-productive land by 34%. Only 11% of the respondents produced gas from bio-energy and one respondent produced heat from biomass. Only 1% indicated that they did not produce their own energy on their land and so it can be assumed that the remaining 100 participants opted not to answer this question.

Table 7: The proportion (%) of the respondents producing their own energy by type.

Type of energy	Proportion of respondents[1] (%)
Wind turbine electric	-
Solar panels on buildings and non-productive land	34
Solar panels on previously cultivated land or grassland	-
Solar panels on currently cultivated land or grassland	-
Gas production from bio-energy	11
Combined Heat and Power	46
Heat from biomass	1
Geothermal energy	-
Hydrothermal energy	-

[1] This question was answered by 70 of the respondents.

When investigating Table 7 further and dividing the data by countries, we can see a large proportion of the farms producing energy from combined heat and power derive from Italy (Figure 4). Notably, zero farms in Iceland produced energy from wind turbines or solar panels of any kind.

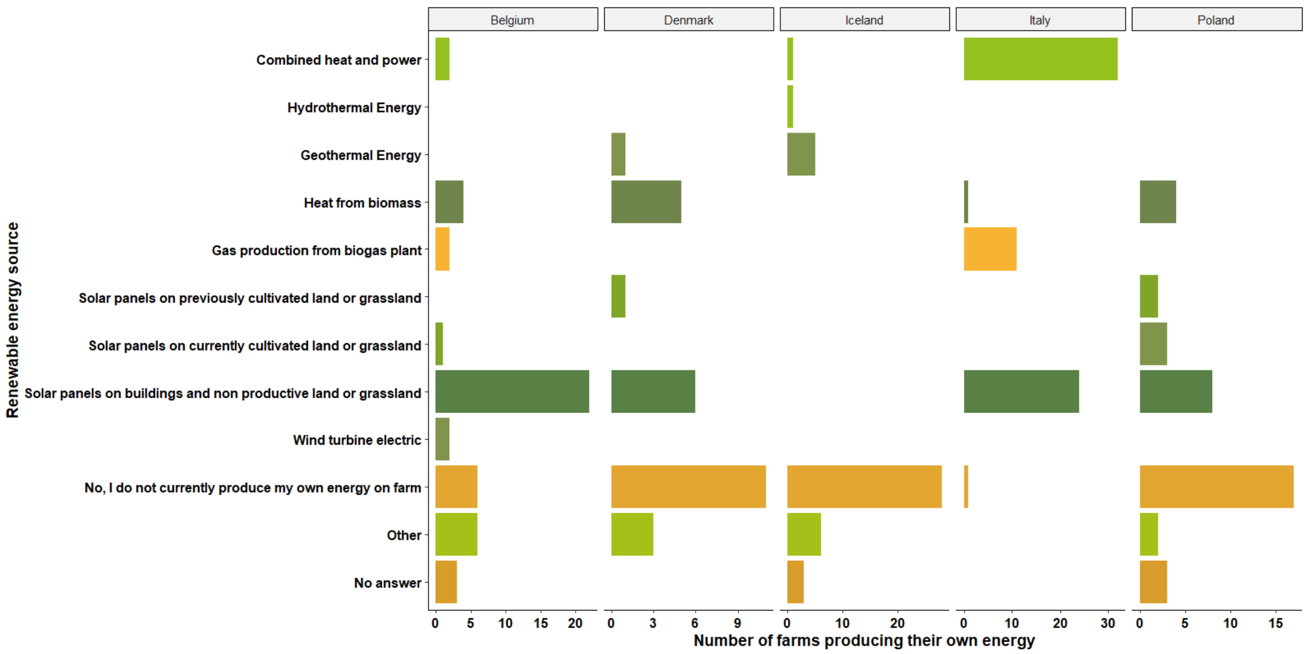


Figure 4: Farmlands utilising renewable energy production across the five participating countries of the project.

Survey participants were asked whether they exported biomass, electricity or gas off their farms. Whilst many did not answer this question, two respondents said they exported biomass for energy, 49 exported electricity and one exported gas.

When participants were asked whether they produced any waste products from their crop or animal enterprises that could be used for energy production, it was found that 38% of them thought they did. Respondents' mean use of energy was stated as 65,898 KWh, although this figure might need to be approached with care due to the wide range of figures presented, as well as several missing responses.

Respondents stated that on average 19% of their total farm business costs were related to the purchase of energy. The on-farm use of diesel, gas and electricity by respondents by type of use is shown in Table 8.

Table 8: Respondents' on farm use of diesel, gas and electricity by type of use (number of respondents).

	Use of:		
	Diesel	Gas	Electricity
On-farm operations (sowing, planting etc.)	140	9	12
Irrigation	12	-	25
Energy use in barns and farm buildings	4	25	114
On-farm post-harvest operations (storage, grain drying)	5	3	15
Horticultural production (e.g. heating glasshouses)	1	2	2
Waste management	3	-	1

It can be seen that diesel was the most common fuel used closely followed by electricity then gas. Diesel was predominantly used for on-farm operations such as sowing and planting and electricity was the most important source of energy for barns and farm buildings; it was also used to a certain extent for irrigation and on-farm post-harvest operations such as storage and grain drying. Gas was mainly used as an energy source for barns and farm buildings.

2.2.3: Interest in energy-related diversification or production

Almost 58% of survey respondents said they were considering investing in energy diversification on their farms in the next five years. Of these respondents, farmers in Italy appeared to be the most inclined towards considering energy diversification with 83% confirming their intent within our survey (figure 5). For all participants who were interested, Table 9 shows which of a range of possibilities applied.

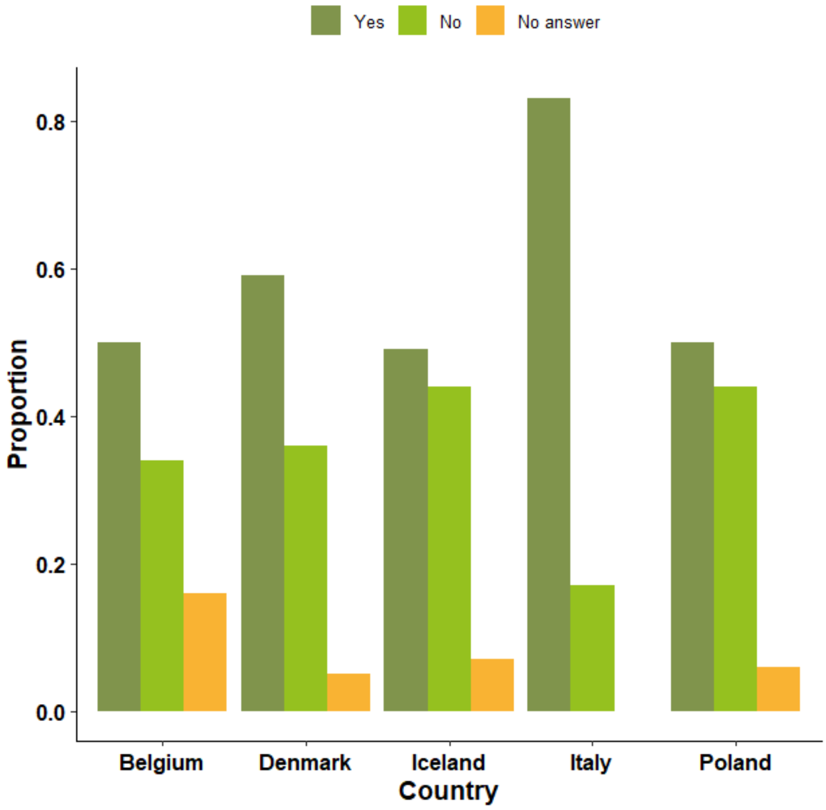


Figure 5: Proportion of respondents per country declaring whether they are considering investing in energy diversification on their farm within the next 5 years.

Table 9: Respondents' interest in investing in various types of on-farm renewable energy production.

Type of energy	Proportion of respondents[1] (%)
Wind turbine electric	21
Solar panels on buildings and non-productive land	62
Solar panels on previously cultivated land or grassland	14
Solar panels on currently cultivated land or grassland	0
Gas production from biogas plant	40
Combined Heat and Power	15
Heat from biomass	12
Geothermal energy	6
Hydrothermal energy	2

[1] Who answered the question. This question was answered by 101 participants

The highest level of interest, shown by respondents, in investing in various types of on-farm energy production was: Solar panels on buildings and non-productive land (by 62%) followed by Gas production from biogas plant (by 40%). Interest in Wind turbine electric was exhibited by 21% of the respondents and in Combined Heat and Power by 15%.

Little interest in investing in four other types of energy production presented on the questionnaire was shown and, perhaps surprisingly, not one respondent said they were interested in Solar panels on currently cultivated land or grassland. These trends were relatively consistent across the participating partner countries, however farmers in Italy were most interested in gas production from a biogas plant, a large proportion of respondents from Belgium and Iceland selected “Other” as an option and these mainly stated Heat Pump energy as their main interested (see figure 6).

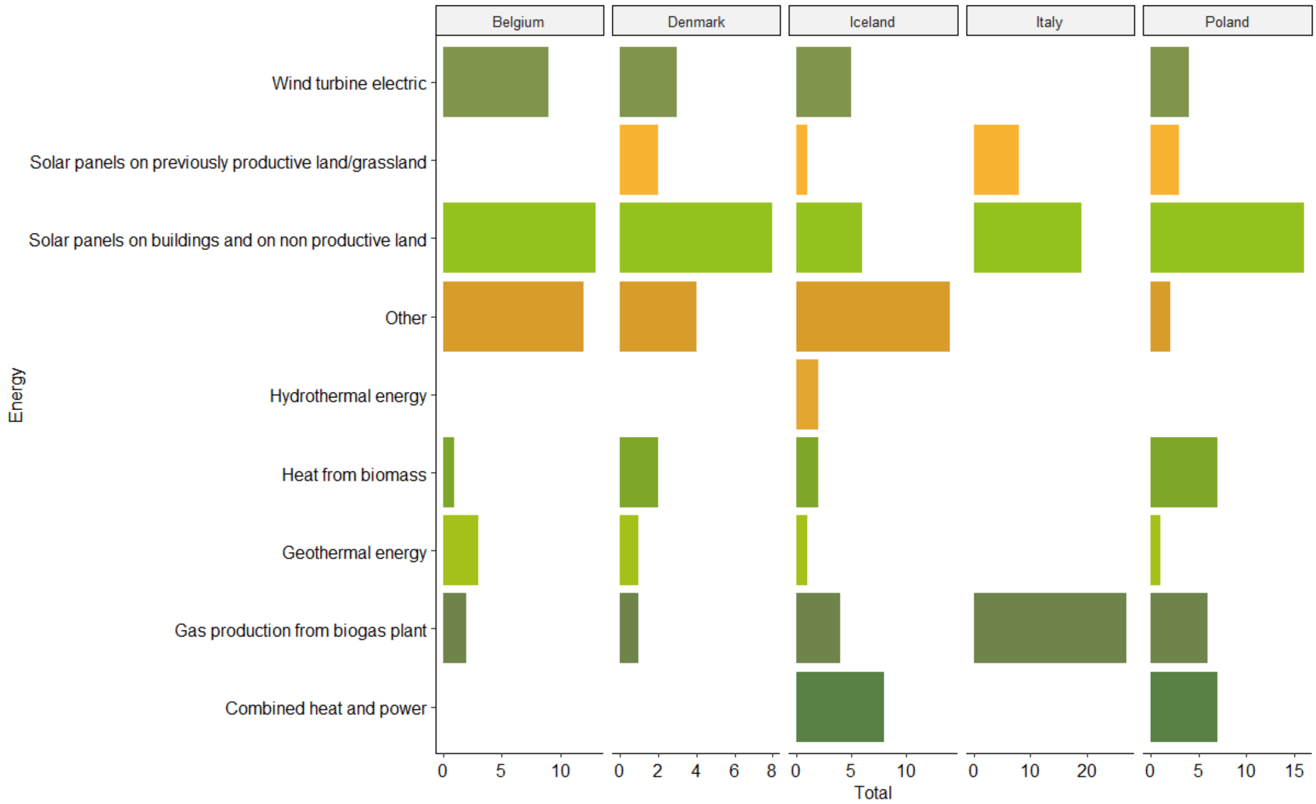


Figure 6: Respondents’ interest in investing in various types of on-farm renewable energy production by country

Respondents were asked what factors might encourage them to implement on-farm renewable energy production. The results of this question which will, no doubt, be of great interest to policy-makers, are shown in Table 10. It can be seen that the most important factor, cited by 84% of the respondents was the provision of grant funding, followed by further increases in energy costs by 49% and provision of low interest loans by 43%. These three factors are financial in nature, so it is interesting to note that some non-financial factors were also cited by substantial numbers of respondents: More information and advice (by 33%); Insecurity of supply from the grid (by 28%); and more demonstration farms (by 24%).

Table 10: Factors that might encourage the respondents to implement on-farm renewable energy production.

Encouragement factors	Proportion of respondents[1] (%)
Provision of grant funding	84
Provision of low interest loans	43
More information and advice	33
More demonstration farms	24
Further increases in energy costs	49
Insecurity of supply from the grid	28
Environmental pressures	18
Increased local uptake by other farmers	11
Creation or presence of co-operatives	14

[1] Who answered the question. This question was answered by 146 participants

Respondents were asked about the importance of a range of eight issues were to them when considering producing renewable energy on their farms; the results are shown in Table 11.

The most important issue of consideration to the respondents was affordable establishment costs which was stated as Very important or Important by 136 respondents, closely followed by income needed for a good financial return by 124 respondents and easily available information and support by 122 respondents. A technology that would not impact my current farming system and simplicity of obtaining planning permission were also seen as important by the respondents. The need for no additional labour or potential impact on any tenancy agreements were not seen as particularly important in consideration of investing in producing renewable energy on their farms.

Table 11: The stated importance of a range of issues to respondents when considering producing renewable energy on their farms.

	Respondents' measures of importance[1]				
Issues relating to renewable energy production	Very important	Important	Not very important	Of little importance	Extremely unimportant
The returns needed for a good financial return	76	48	8	1	11
Affordable establishment costs	71	65	6	1	1
A personal understanding of the technology	42	77	18	5	3
The need for no additional labour	37	55	28	12	7
Impact on any tenancy agreements	15	30	36	21	29
Simplicity of obtaining planning permission	56	54	14	12	3
A technology that would not impact my current farming system	49	53	32	3	2
Easily available information and support	59	63	15	5	1

[1] Number of respondents citing each level of importance.

The respondents were questioned on their views on the importance of a range of possible benefits to them from producing on-farm renewable energy on their farms; seven possible benefits were listed and the results are shown in Table 12.

Table 12: The perceived importance of a range of possible benefits to respondents from producing renewable energy on their farms.

	Respondents' measures of importance[1]				
Possible benefits from renewable energy production	Very important	Important	Not very important	Of little importance	Extremely unimportant
Improve farm profit	85	60	7	1	2
Reduce pollution	61	56	17	7	5
Reduce the farm's carbon footprint	61	54	17	7	10
Provision of better security of energy supply	57	65	19	3	4
Easy integration within my current system	54	61	23	3	4
Improved use of current residues	44	60	22	12	9
Improved sustainability of my business	61	63	16	2	2

[1] Number of respondents citing each level of importance.

The most important perceived benefit listed by respondents from producing on-farm renewable energy on their farms as very important or important by 145 respondents was Improve farm profit, followed by improved sustainability of my business by 124, provision of better security of energy supply by 122, reduce pollution by 117, Reduce the farm's carbon footprint by 115 and Easy integration within my current system by 115. When considering these results overall, it can be concluded that the respondents found a wide range of important possible benefits from undertaking on-farm production of renewable energy production. This finding will be of interest to policy-makers.

2.2.4: Training and knowledge needs

The final section of the questionnaire concentrated on ascertaining future training and knowledge needs of the respondents with respect to implementing on-farm renewable energy production; summary results are presented in Table 13 where respondents stated the importance of training areas in relation to renewable energy production.

Table 11: The stated importance of potential future training areas to respondents in relation to on-farm renewable energy production.

	Respondents' measures of importance[1]				
Potential areas of training	Very important	Important	Not very important	Of little importance	Extremely unimportant
Diverse crop rotations	47	64	24	9	7
Agrivoltaics	32	51	31	13	10
Wind power	24	38	36	13	19
Anaerobic digestion	38	40	32	17	17

[1] Number of respondents citing each level of importance.

If we consider importance of their responses as linking Very important or Important together, Diverse crop rotations was the most important stated potential area of training needs with 111 respondents. Agrivoltaics was the next most important area with 83 respondents, followed by Anaerobic digestion by 78; Wind power, with 62 respondents, was well behind the listing of importance.

Survey participants were asked what were their preferred formats for the provision of training and knowledge materials relating to the adoption of on-farm renewable energy production; Five format options were provided for their choice. Perhaps not surprisingly considering the fact that the majority of the respondents were over 50 years of age, 87 respondents preferred in-person workshops/demonstrations whereas 43 preferred online workshops/demonstrations and 45 Video presentations. Audio and Paper based formats were preferred by 9 respondents together.

The last question of this final section of the questionnaire was: Would you like to join an End Users Advisory Board of the project to provide feedback on the progress of the Value4Farm project. Interestingly, some 33.53% (or 457) of the respondents have signed up to join the Board.

2.3 Summary

Description of respondents

The survey, based on responses from 170 farms, revealed a diverse range of farm sizes, with a mean of 154 hectares and a wide range from 0.1 to 1400 hectares. Cereal production emerged as the most common land use, accounting for 71% of respondents, with an average area of 75 hectares per farm. Following closely were grass leys (59% of farms) and permanent pasture/rough grassland (48% of farms). Horticulture under glass was the least common land use, practiced by 18% of respondents with a mean area of 0.4 hectares. The tenurial arrangements on these farms were predominantly owner-occupied (76%), followed by long-term rental agreements (33%), while share farming was the least common form, found on 16% of farms.

In terms of livestock, dairy cattle were the most prevalent, present on 42% of farms, with an average of 151 cows per farm. Sheep and pigs were also common, found on 31% and 48% of farms, with mean numbers of 76 and 2083.4 head, respectively. Miscellaneous livestock, including alpacas, horses, goats, donkeys, rabbits, and mink, were also reported. On average, farms had 3.4 full-time workers and 5.9 part-time workers, including family members. Respondents were predominantly male (82%), with an average age of 54. About 34% had identified a successor for their farm, while 40% were unlikely to or had not identified one. Almost 40% of household incomes came from sources other than the farm business. Regarding the viability of their farm business, 5% considered it not profitable and potentially unsustainable, while 7% were increasing profits. Cooperative participation was observed, with over 35% belonging to a selling cooperative and 14% to a buying cooperative.

Energy Use and Production: Key Findings and Recommendations

The survey focused on energy use and production in agriculture, with 96% of respondents relying on National Grids for electricity, 28% for gas, and 52% for heat. Combined Heat and Power was the most common self-produced energy , followed by electricity from solar panels .

Diesel was the most common fuel, especially for on-farm operations. Electricity was crucial for utilities within barns and farm buildings, irrigation, and post-harvest operations. Gas was mainly used for heating barns and farm buildings.

58% of respondents had or were considering investing in energy diversification. Solar panels on buildings and non-productive land and gas production from bio-digestion were the most favoured options. [62%]. Some 38% of the respondents said they produced waste from crop and animal enterprises that could be used for energy production.

Grant funding (84%), increased energy costs (49%), and low-interest loans (43%) were key motivators in terms of encouraging uptake. Non-financial factors like information and advice (33%) and demonstration farms (24%) were also considered to be important.

In terms of considering establishment of renewable energy infrastructure then affordable outlay costs, income to provide a good financial return, and easily available information and support were top considerations. Minimal impact on current farming systems and ease of obtaining planning permission were important to respondents.

In terms of perceived benefits of renewable energy production farmers noted improved farm profit, enhanced sustainability, and better energy security were the most important.

Knowledge of more diverse crop rotations, agrivoltaics, and anaerobic digestion were identified as key training needs. Preferred formats for training were in-person workshops/demonstrations (87%).

Recommendations

Government or industry initiatives could focus on providing grant funding and low-interest loans to encourage renewable energy adoption.

Educational programs should prioritise knowledge about more diverse crop rotations, agrivoltaics, and anaerobic digestion.

Researchers on V4F should consider farmers' preferences for in-person workshops/demonstrations when designing outreach programs.

2.4 Focus Group Discussions

2.4.1 Methodology for in-person focus group discussions with farmers and stakeholders

A series of focus group discussions with farmers and related stakeholders was conducted for two purposes: to establish end-user needs for incorporating renewable energy production into agriculture specifically related to crop protocols suggested in the Value4Farm proposal; and to further investigate some of the findings from the farmer survey. Such discussions were intended to be held in M5 (January 2024) in the demonstration and replication site countries.

Initial consideration of the design of the focus groups was made at the full project start-up meeting in M2; UREAD worked on focus group design in the following two months. They devised a two-part discussion guide for the five partners who were to carry out the focus groups. UREAD suggested that these should consist of a chair, a facilitator and 6-7 other participants (farmers and stakeholders). Furthermore, it was also suggested that the procedure should take no more than 120 minutes and that discussions should be recorded and refreshments provided.

The draft discussion guide focussed, first, on a detailed presentation of the energy production crop protocols. This was intended to ascertain participants' views on their feasibility of introduction and ease of implementation on farm. This information was gathered via SWOT analysis. The second part of the guide consisted of at least five most important findings of the survey for more in-depth discussion; these were derived from an initial perusal by UREAD of the replies of the first 40 survey responses. A final part of the focus group focussed on user "stories'" which would aid the construction of the DST, reported on later in this deliverable.

The draft discussion guide was sent to partners in early M4 with their comments and suggestions enabling the production in early M5 of the final version. This guide was then approved via UREAD's ethical clearing procedure. Partners in the five demonstration/replication countries completed a focus group, the summaries of which are presented below, with the full proformas available in appendix 2. Table 14 provides an outline of the number and type of stakeholder at each focus group.

Table 12: Location of focus groups and stakeholders present

Location	**Project staff**	**Farmers**	**Advisors/Policy**	**Industry/Contractor**	**Total non-project Participants**
Belgium	3	7	1		8
Denmark	3	3	1	2	6
Iceland	3	6	3		9
Italy	2	4	2	2	8
Poland	2	3		1	4
Total		**23**	**7**	**5**	**35**

2.4.2 Findings of each Focus Group discussion

Focus groups were completed over a period of 15 days, some being in person and some hybrid. Partners provided a comprehensive record of the meetings translated into English. A summary of each of the meetings is provided below under the country heading. A full written record of the meetings is available upon request.

Belgium

Background

This Value4Farm Focus Group was held on January 23, 2024 to discuss the project's protocols and demonstrations. The meeting at INA in West Flanders was comprised of 11 participants, including a facilitator, reporters, a policy maker in renewable energy, and various farmers with different agricultural backgrounds.

The meeting began with introductions and an overview of the Value4Farm project's goals, focusing on feedback for protocols and the Belgian demonstration case. This involves sustainable energy use through biogas, providing a bottom-up approach by involving farmers in decision-making.

SWOT Analysis

Participants engaged in a SWOT analysis, identifying internal and external factors. Strengths included agri-residue valorization and circular energy production, while weaknesses ranged from limited stakeholder knowledge to unclear/uncertain legislative frameworks. Opportunities for progressing further included subsidies and initiatives that reduced transport, while threats involved inconsistent legislation and the potential competition with hydrogen as an alternate "renewable" gas.

Questionnaire follow up

A number of questions were informed by the questionnaire. Most participants knew their electricity consumption, with many actively managing energy through solar panels and other technologies. Concerns were raised about profitability, grid injection prices, and complexities in energy production. Barriers to biogas use included labour intensity, permit difficulties, and the need for qualitative input streams.

User Knowledge Needs

Participants expressed a need for decision support tools, seminars, and accessible information to implement the Value4Farm technologies. Farmers emphasized the challenge of staying informed amidst rapidly evolving technologies, policies, and markets. They sought clear planning, 1-on-1 guidance, and incentives for energy production.

Recommendations

- Initiate seminars and design online resources to up-skill farmers on evolving technologies, policies, and market dynamics.
- Develop a user-friendly decision support tool providing basic measurements and filtering relevant information for individual farms.
- Advocate for clearer legislative frameworks and consistent subsidies to encourage renewable energy investments.
- Propose government-supported initiatives, including 1-on-1 guidance for farmers considering renewable energy solutions.

- Expand efforts to set up demonstrations and pilot cases showcasing new technologies, providing farmers with firsthand experiences.
- Collaborate with farmers and energy cooperatives to demonstrate the feasibility and profitability of cooperative biogas plants in the region.

Denmark

Background

The Value4Farm project held a focus group meeting on the 30th January 2024 in Denmark bringing together diverse stakeholders from the agricultural and energy sectors. Key topics included Agrivoltaics, biorefining, and biogas biomethanisation. The session featured a SWOT analysis, addressing challenges like field conversion, logistics, stakeholder conflicts, and machinery adaptation. The meeting emphasized the challenge of societal acceptance, the efficient use of cover crops, and financial considerations.

SWOT Analysis

The proposal to build energy facilities near streams and rivers has the strength of reducing nitrogen leaching, providing dual benefits of protein production and energy generation. This could create an appealing narrative and present exciting income opportunities for farmers. The group noted that the protocol for the Atlantic pedagogic region offers opportunities to minimize waste, ensure nutrient suitability, and could integrate with robots for efficient field management, aligning with potential future agricultural subsidies and sustainable practices.

However, notable challenges were discussed, including the lengthy process and difficulties in obtaining grid connections, especially in more remote areas. The use of special machines in smaller facilities may not be cost-effective, and concerns about potential conflicts, soil compaction, and damage to solar panels pose threats to the overall feasibility. Achieving self-sufficiency at different scales and addressing logistical issues while considering neighbourhood impact were discussed as potential obstacles that need careful consideration and strategic planning.

Questionnaire feedback

Feedback from questionnaires provided information on farmers' energy consumption practices and challenges. Farmers are conscious of energy sources with some exploring strategies like optimized cultivation and solar installations to improve energy efficiency. Concerns included location selection, national regulations, and the impact on agricultural land of energy production. Biogas discussions revealed some scepticism about its future viability, with more positive discussion related to electrification. Biomass utilization debates centred on efficient straw use and concerns about future biomass availability.

User Knowledge Needs

The group identified the diverse knowledge needs for implementing Value4Farm technologies. Stakeholders called for clearer political guidelines on biogas expansion, a need to address challenges in the electricity infrastructure, and exploring potential in the heavy transport sector. Farmers express frustration about the lack of political support for local biofuel use, particularly in district heating. Concerns about the "black tax" impact on biogas for transport and tailoring solutions to regional needs were also raised.

Recommendations

- Simplify procedures for grid connections, especially in remote areas, to expedite the integration of energy facilities. Highlight benefits like reduced nitrogen leaching and dual protein-energy production.
- Advocate for agrivoltaic system adoption, emphasizing waste reduction, nutrient suitability, and robotic integration. Showcase income opportunities and environmental benefits to farmers.
- Acknowledge issues of specialist technology in smaller facilities and seek cost-effective solutions. Implement pilot projects and collaborative efforts to demonstrate feasibility and resolve logistical concerns.
- Provide clear political guidelines on biogas expansion, addressing concerns about viability and promoting its potential in electrification. Tailor guidelines to encourage sustainable growth, considering local and regional needs.
- Advocate for political support for local biofuel, particularly in district heating. Develop policies that incentivize local biofuel production, addressing concerns about the "black tax" impact on biogas for transport. Tailor solutions to regional needs.

Iceland

Background

On January 29th, 2024, the Icelandic Value4Farm Focus Group took place, discussing the Value4Farm project, its protocols, and demonstrations, see figure 7. The meeting was a hybrid with on-site and online participation due to severe weather conditions and travel distances. Nine participants, including farmers, agricultural advisors, and consultants, discussed the project's objectives and concepts.

SWOT Analysis

The participants engaged in a SWOT analysis, identifying strengths like the availability of organic biomass and market demand for methane. Weaknesses included a lack of storage capacity, diverse biomass composition, and insufficient knowledge of potential users. Opportunities included green branding, carbon credit business cases, and biomass valorisation, while threats encompassed weather conditions, unclear regulations, and economic feasibility concerns.

Questionnaire Feedback

In further exploring survey responses, farmers expressed interest in energy production but highlighted concerns about the significant capital costs of biogas plants. The participants discussed managing energy consumption, prioritizing energy projects and fertiliser options, and challenges associated with switching away from inorganic chemical fertilisers.

User Knowledge Needs

Farmers and stakeholders were able to articulate their knowledge needs. They emphasised the necessity for additional storage facilities, adapted equipment, and a clear understanding of the potential benefits, commercial viability, and requirements for implementing Value4Farm technologies. Agricultural advisors sought information on storage facilities, biomass collection, and infrastructure requirements, particularly related to horticultural production.

Recommendations

- A need to address the lack of storage capacity and general infrastructure, providing farmers with more information on the necessary equipment and mechanisms. Additionally, invest in training programs to enhance knowledge about biogas and biofertilizer production.
- A requirement to further explore financial support mechanisms, such as EU Investment and Nordic Investment Bank, to encourage farmers' participation and to mitigate switching costs. Create incentives, like carbon credit schemes , to make participation in cooperative (COOP) models economically viable.
- Advocate for clearer laws and regulations to facilitate the licensing process for biogas and biofertilizer production and to engage municipalities in projects, ensuring alignment with local planning and land use.
- Address the "Not in My Back Yard" (NIMBY) sentiment by fostering community awareness and engagement via emphasis on the environmental benefits and potential economic advantages of implementing biogas and biofertilizer projects.
- Invest in further research to address concerns about the composition and effectiveness of biofertilizers compared to chemical fertilizers. Conduct cost-benefit analyses to showcase the economic viability and environmental benefits of these technologies.

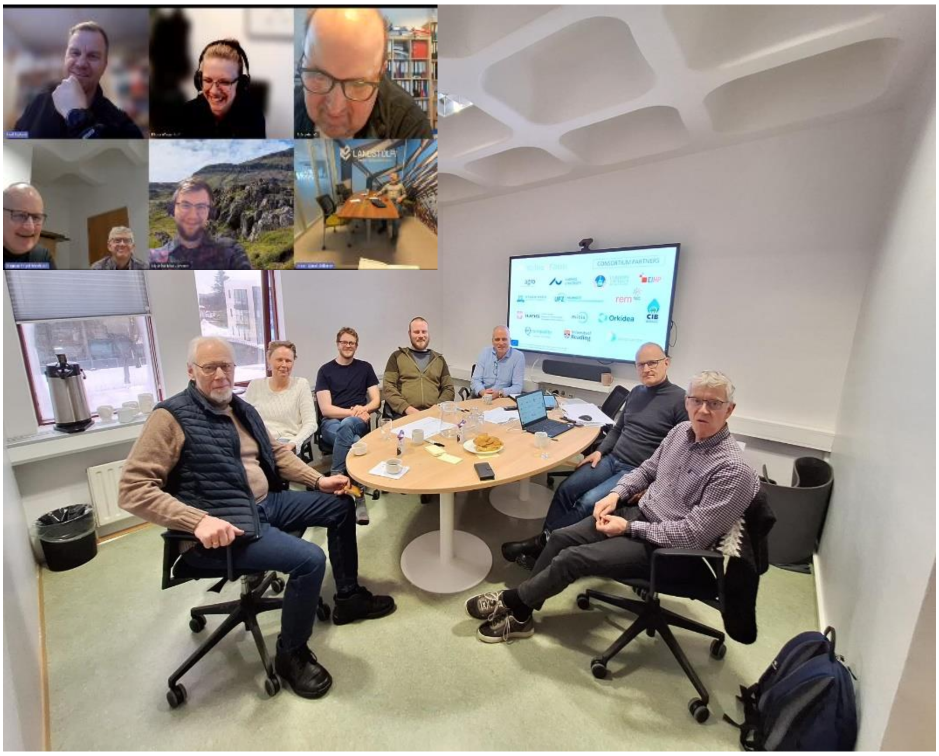


Figure 7: Focus group discussions during OKD’s workshop.

Italy

Background

On January 30th, 2024, a focus group meeting for the Value4Farm project was conducted in Italy, organized by CIB. The meeting discussed the protocols within the project and the results from the questionnaire. The focus group took place in Lodi, Italy, an area known for its high density of biogas plants.

SWOT Analysis

After introducing the Value4Farm project, a SWOT analysis was conducted by participants. Strengths included the opportunity of more circular production, resource optimization, and sustainability enhancement. Weaknesses noted included the need for knowledge of the techniques involved and the more complex management of biomethane. Opportunities encompassed a further reduced environmental impact and the further diversification and sustainability of agricultural production. Threats included technical challenges with biomethane machinery and potential competition with other new fuels, for instance hydrogen.

Discussion of Questionnaire Outputs

The questionnaire feedback revealed that farmers were aware of their electricity consumption but faced challenges in determining or at least apportioning overall energy usage. Farmers invested in biogas plants for sustainability, cost reduction, and circular economy benefits. All believed their farms would survive without bioenergy, but with less positive economic and environmental outcomes. Farmers recommended biogas investments to those seeking income diversification and environmental improvement.

User Knowledge Needs

The participants expressed individual perspectives on the need for specialized knowledge and support in managing complex and integrated energy models. Farmers emphasized the importance of expert guidance, simple tools, and specialized support for successful integration of energy production into their farms. They also highlighted the necessity for pilot plants, tests, and direct knowledge of new solutions for informed decision-making.

Recommendations

- Ensure the provision to farmers of specialized support and knowledge to navigate the complexities of integrated energy models.
- Pilot plants and testing opportunities should be made available to facilitate informed decision-making.
- Recognizing and rewarding environmental services provided by sustainable farms could further incentivize adoption.
- Ensuring ongoing research and scientific data on emerging technologies like agrivoltaics to address farmers' concerns and encourage future investments.
- Exploration of cooperative biogas plants as a potential solution for small farms, and continued support for such initiatives should be considered.

Poland

Background

On 2nd February 2024, an online focus group meeting for the V4F project took place in Poland, specifically in the Lubelskie Voivodeship, utilizing the ZOOM platform. The meeting was convened to discuss the potential replication of biogas production and field protocols for the Atlantic region in the Polish context. Participants included stakeholders, farmers, and project team members, engaging in discussions about the project's objectives, biogas production protocols, and their applicability in Poland.

SWOT Analysis

The SWOT analysis focused on general conditions for biogas production in Poland, rather than the specific protocol. Strengths included a compromise between food and energy production, improvement of soil structure, economic gains, and the fact it was a generally “known” agrotechnology. Weaknesses discussed included the potential lack of acceptance for targeted crop rotation for biogas production and challenges related to the intentional cultivation of biomass for digesters when there are many other sources of substrates. Opportunities included on-farm energy production and surplus manure utilization, while threats encompassed low public acceptance, low profitability in selling energy to the grid if it was not used very locally, and concerns about using manure as a substrate when it had other uses/

Questionnaires

The focus group analysed feedback from questionnaires, addressing topics like current farm energy usage, management of farm activities to control energy use, barriers to biogas generation, and utilization of waste streams. Farmers expressed awareness of energy consumption and concerns about barriers such as high investment costs for biogas compared to other renewable energy sources.

User Knowledge Needs

Knowledge gaps were identified among participants, with farmers expressing a desire for more information about technology, funding opportunities, and potential advantages of biogas production. Stakeholders were interested in broader project objectives and results. Specific user stories highlighted individual needs, such as a farmer wanting a model for implementing a small biogas plant for waste heat in greenhouses.

Recommendations

- The potential to conduct targeted education and outreach programs to address knowledge gaps among farmers, emphasizing the benefits and practical aspects of biogas production.
- The need to align biogas production initiatives with existing agricultural policies to encourage wider acceptance and integration into farming practices.
- Consider providing financial support mechanisms, such as subsidies or favourable loans, to incentivise on-farm energy production and infrastructure development.
- Produce biogas production models to suit the needs of diverse farms, considering the scale and resources available, also focusing on small-scale and organic farming.
- Potential to develop public awareness campaigns to improve acceptance of biogas plants, emphasizing the environmental benefits and dispelling misconceptions.

Overall recommendations from the 5 focus groups

General Recommendations arising from the focus groups

Specialized Support and Knowledge for Farmers: Ensure the provision of specialized support and knowledge to farmers to navigate the complexities of integrated energy models. This includes targeted education and outreach programs to address knowledge gaps and emphasize the benefits and practical aspects of various sustainable energy practices.

Pilot Plants and Testing Opportunities: Facilitate informed decision-making by making pilot plants and testing opportunities available. This will allow farmers to view and input into the use of different technologies and choose the most suitable and effective options for their specific circumstances.

Recognition and Rewards for Environmental Services: Recognize and reward environmental services provided by sustainable farms. Incentivizing adoption through recognition can encourage farmers to integrate environmentally friendly practices into their operations.

Ongoing Research and Scientific Data: Ensure ongoing research and scientific data on emerging technologies, such as agrivoltaics, to illustrate the positives to farmers and to alleviate their concerns and encourage future investments. This will contribute to building trust in new technologies and practices.

Biogas-Specific Recommendations

Align Initiatives with Agricultural Policies: Align biogas production initiatives with existing agricultural policies to encourage wider acceptance and integration into farming practices. Incentives and concessions to mitigate the economic impact of switching costs.

Diverse Biogas Production Models: Produce biogas production models that suit the needs of diverse farms, considering scale, resources, and focusing on small-scale and organic farming. It is likely that regional specific initiatives and demonstrations tailored to “local” farming systems will have the greatest impact.

Address Storage Capacity and Infrastructure: Overcome some of the concerns about storage and general infrastructure for biogas production. Provide farmers with more information on necessary equipment and mechanisms, and invest in training programs to enhance knowledge.

Cooperative Biogas Plants and Financial Support: Explore cooperative biogas plants as a potential solution, especially for small farms, and provide continued support for such initiatives. Consider financial support mechanisms, such as subsidies or favourable loans, to incentivize on-farm energy production and infrastructure development.

Agrivoltaics-Specific Recommendations

Simplify Grid Connections and Highlight Benefits: Simplify procedures for grid connections, especially in remote areas, to expedite the integration of agrivoltaic systems. Highlight benefits like reduced nitrogen leaching and dual protein-energy production.

Advocate for Agrivoltaic Adoption with Demonstrations: Advocate for agrivoltaic system adoption, emphasizing waste reduction, nutrient suitability, and the potential for future robotic integration. Showcase income opportunities and environmental benefits to farmers through demonstrations and pilot cases.

Address Specialist Technology Issues in Small Facilities: Acknowledge issues of specialist technology in smaller agrivoltaic facilities and seek cost-effective solutions. Implement pilot projects and collaborative efforts to demonstrate feasibility and resolve logistical concerns.

3. DECISION SUPPORT TOOLS FRAMEWORK (TASK 1.4)

3.1 Aim

The main aim of this work is to expose the wider farming community across Europe to the concept of producing both food and energy from their land and in particular showcasing some of the lessons learnt and practical outcomes from the Value4Farm project demonstration and replication sites through an *OOC (Online Open Course).* For those farmers wanting to further explore this integrated concept an *Audit Tool* will consider the potential options in their particular situation to help identify the type of system that may be most appropriate. If the farmer then wants to consider specific options in practice a *Transition Tool* will outline the practicalities and cost elements that will help enable initial decision-making.

3.2 Review of existing literature

An extensive literature review has been conducted (see Appendix 1) that covers a description of the term "decision support tools", their current uptake by farmers, and reasons for (non)adoption and use. A critical review of 63 current DSTs is also included (see description of DSTs reviewed in Appendix 1).

Overall, there appears to be an extensive range of DSTs available on a wide range of aspects of farm and agricultural management. Some are aimed at farmers, advisors / agronomists, and some at those associated with farm businesses (e.g. accountants), policy maker and ecologists / environmentalists associated with farming.

In general, there appear to be few DSTs which consider both energy and food production in agricultural settings. The majority focus on food production (crop management), considering how to improve yields and reduce or apply inputs (e.g. fertilisers or pesticides) more effectively. An increasing number of DSTs consider carbon and greenhouse gas emissions, and as part of this may consider how to reduce energy use or introduce renewable energy generation on farms. There were also a number of DSTs (not recorded as part of this review) focussing on aspects of farming and land management such as water quality, soil health and pollution reduction.

In terms of design or set-up, many DSTs and Decision Support Systems (DSSs) offer the opportunity to bring together various farm level data in an app which can then support decision making by farmers. Some offer a "flow chart" style decision support, some an audit, a course, a knowledge space (which can be personalised, bringing together specific news, reports and research), data aggregation and collation to aid decision making, some offer case studies, compliance advice and guidance and links to information about subsidies or agricultural products.

The majority of DSTs found were available in English (although the search process may have been biased towards finding DSTs in English). Some were also available in alternative or multiple alternative languages. In some cases (depending on the format of the DST) Google translate may be able to support use of the DST if it is not available in a user's native language.

Regionality may also be important aspect to consider. While many of the DSTs found appeared to be widely geographically applicable, for example through using Earth Observation (EO) or Geographic Information System (GIS) data to support mapping and recording data, or relying on farmer inputted data, some were specific to a country or region. In these cases the DST may have been supporting decision making on specific aspects of farm management, such as compliance regulations which were specific to a country, or relating to the climate or crops grown in a particular region (for example olive growing in mediterranean regions).

The DSTs found during this review were developed and produced by a variety of organisations, research projects and companies, some not-for-profit, some businesses. Some were freely available and some charged for. Some may have a free, more basic, DST and charge for similar DSTs with an increased number of functions, some were subscription-based or required membership of the developing organisation.

Five existing similar/relevant Open Online Courses were identified as part of this review. These mainly focus on aspects sustainable or regenerative farming in relation to food production. Once focuses on 'electric farming' in the United States of America. None of these courses focus on both renewable energy production *and* sustainable food production in Europe.

The maintenance and sustainability of DSTs may also be an issue. Some DSTs reported in peer-reviewed literature (e.g. found through Web of Science searches) or evaluated as part of review papers are now unavailable. The hosting website may no longer be live or maintained. It is also worth noting that some research papers describe the development of a prototype DST which may not lead to a fully developed, widely available DST.

3.3 Co-design of the decision support tools

The developments of the DSTs will be informed further by the results from the farmer survey and focus groups (Task 1.1). A full analysis of these results will be completed as part of Task 4.5 (Development and Optimisation of the decision support tool) in order to adapt the content to meet the current knowledge needs. Results from the survey suggests that the topics farmers are in most need of more information relate to: i) diverse crop rotations > ii) agrivoltaics > iii) anaerobic digestion. There is also an interest in on farm wind generation in some countries, figure 8.

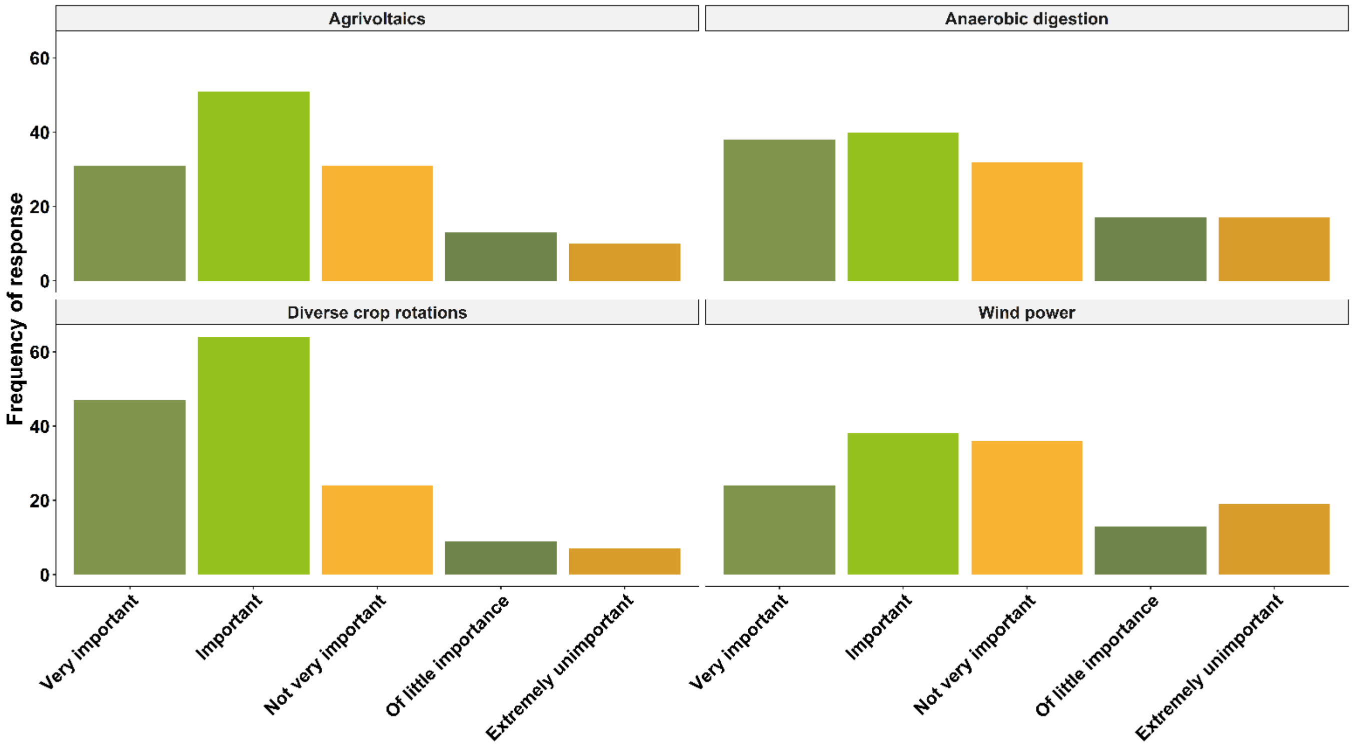
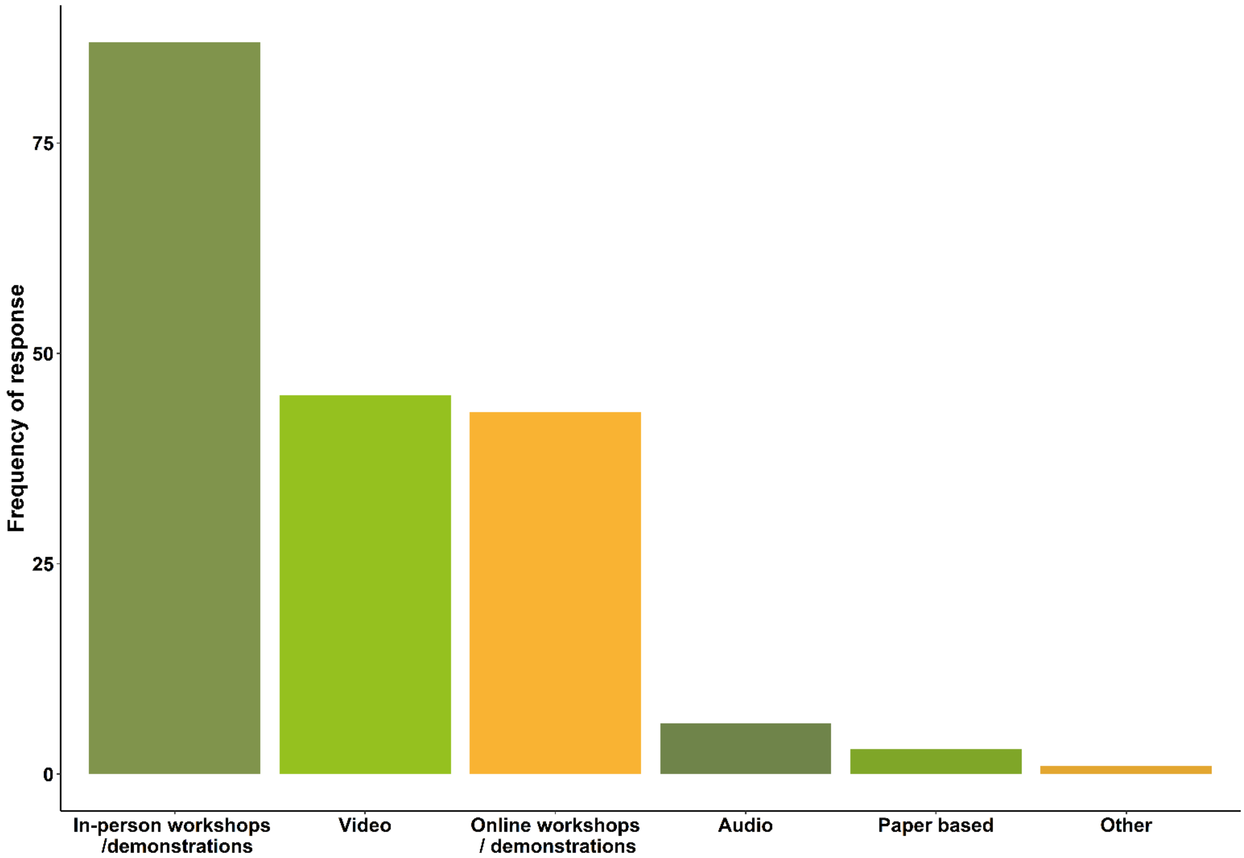


Figure 8: Perceived importance of required training by participants.

The results also show that farmers would prefer to receive training and information on the production of biogas and electricity on farms predominantly in the form of workshops (Figure 9). Therefore, the OOC will need to include recordings of workshops and videos from the demonstration/replication sites to provide that opportunity for peer-to-peer and experiential learning.



The

Figure 9: Preferences of learning and training formats regarding green energy production on farms.

Focus Groups (Task 1.1) asked the participants to consider their knowledge needs to be able to transition to integrated food and energy production. The methodology and results are described in Section 2.1.7. These tables summarise the main knowledge barriers that were mentioned (Table 14) and the current knowledge needs (Table 15). The final table summarises the key aspects that should be taken into account when designing the Decision Support Tools (Table 16).

Table 13: Knowledge barriers identified in the Focus Group discussions

Knowledge barriers	Country
Legislative, taxation and regulatory frameworks aren't clear (in terms of products and permits) and uncertain future	BE, IS, DK, PL
Unclear on subsidies and finance for green energy production and/or carbon credits	BE, IS, DK, PL
Working with contractors therefore don't know energy/oil consumption	BE
Profitability depends on multiple, changing factors (very complex) and can be unprofitable to sell to the grid	BE, IS, PL, IT
Need practical solutions for new equipment, transportation and establishing waste storage facilities	IS, DK, PL
Lack of interest – need help/incentives to move away from imported fertiliser	IS
Societal acceptance	DK, PL
More (societal) emphasis on food production from agricultural land	DK
Access to ready-made solutions/instruments for small scale and organic farms	PL
Protocols require experience to work well	IT

Table 14: Knowledge needs identified in the Focus Group discussions

Knowledge needs	Country
Systemic review of all farming operations needed (start with knowledge of own energy consumption and optimise from there)	BE
Main parameter is 'return on investment' – want a business plan	BE, DK
Information on energy communities/cooperatives, energy sharing (and reducing associated risks) and infrastructure	BE, IS, DK
Options for input streams for biogas plants (e.g. pig manure)	BE
Ways to valorise the CO_2 from biogas plants (e.g. into wineries or in greenhouse horticulture?)	BE, IS
Optimal protocols for waste streams and best valorisation options	IS
Information about protein crops e.g. lupin in rotations	DK, IS
Research into (logistics and benefits of) strip management with agrivolatic installations	DK, IT
Impact on nitrogen (inputs, fixation, leaching)	IS, DK
Evidence-based practice and knowledge of how to combine forms of production from same piece of land with financial information	DK, IT
Certification (e.g. of CO_2)	DK
Knowledge about fermentation process and potential loss of nutrients	PL

Table 15: Important aspects for consideration in the DST

Decision Support Tool	Country
Simple tool, clear vision	BE
Include basic measurements	BE
Filter most relevant information	BE
Demonstrations, seminars, website, pilot cases, 1-to-1 guidance	BE, PL, IT
Sharing of knowledge with inputs from academics, agricultural advisers etc	IS
Distinguish between self-sufficiency in two models – i) on farm circular system and ii) regional level (co)operations	IS, DK, PL
Cost-benefit analysis	IS, PL
Need to consider regional differences and differences farm size	DK, PL
Carbon capture calculations	DK
Tools to provide evidence e.g. of sustainability, green certificates	DK, IT

Almost all participants in the focus groups indicated that they know their electricity consumption. In relation to the design of the transition/audit tools, several participants in the Belgian focus group mentioned "the main parameter for deciding to invest in a certain technology is the Return On Investment" and that "the first step is always to exactly know your energy consumption and profile". These comments will be useful in structuring the audit and transition tools. This focus group suggested that decision support is needed as "energy is becoming more and more complex and the profitability is always depending on multiple factors, which makes it really difficult to make the right investment choices".

In addition to some of the practical elements that farmers need to consider, there were also several comments that related to the finance, labour and skills needed on-farm to implement these V4F protocols. All focus groups identified the need for greater availability of support, knowledge, shared experience and expertise in these issues, justifying the development of the V4F tools.

3.4 Framework for the OOC, audit and transition tools

3.4.1 Open Online Course

The Open Online Course with a working title of "Integrating Food and Energy production on farmland" will be hosted on the FutureLearn platform (https://www.futurelearn.com/) which facilitates the delivery of online courses to a range of audiences. UREAD will work with a team of experienced OOC developers based at the University to develop, produce and format the content. The aim is to engage 2,000 learners in the first two iterations on the FutureLearn platform. The target audience for the OOC will include farmers, advisors, policy makers, agricultural agents and interested members of the public. It is anticipated that the course will last 2 weeks with approximately 3 hours of self-guided learning content each week. While the FutureLearn platform and the majority of the OOC will be in English, some sections may be made available translated into additional languages, video or audio content may be available subtitled in additional languages. Decisions on translation will be made on a case-by-case basis and will depend on the material. For example, video or audio content recorded on a Value4Farm demonstration site could have subtitles in additional languages. Sections of the OOC may be offered in languages other than English as a separate document for learners to download.

At the start of Task 4.5 (July 2025, month 23), the V4F partners involved will attend a Rapid Course Build workshop with the development team. To ensure the OOC will be based on sound pedagogic principles, the workshop will cover the learning pedagogy, the learning cycle, characterisation of the learner (using personas), the learning objectives for the course and develop activities that suit a range of learning types (investigate, practise, collaborate, read/watch/listen, discuss and produce).

The OOC content will be informed by outcomes from the farmer survey and focus groups undertaken as part of WP1 (as described in Section 2), in conjunction with exploration of the literature and expertise of Value4Farm partners in understanding the needs and knowledge gaps of the target audience. The main collaboration will be between UREAD and WUR for content development, leveraging their successful OOC experiences, working with the central OOC development team at Reading. The content will align with the 2030 Agenda for Sustainable Development by addressing the following Sustainable Development Goals

- Goal 2 Zero Hunger (Target 2.4 – ensure sustainable food production systems and implement resilient agricultural practices)
- Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all (Target 7.2 – increase the share of renewable energy in the global energy mix)

Broadly, the OOC will offer an overview of the growing importance of integrating food and energy production in sustainable agriculture and provide a rationale for addressing both food and energy production in farm management. It will also give an overview of the energy technologies available to farmers with a particular focus on those related to the Value4Farm project (with mention of the V4F project throughout the OOC). It will outline of benefits and challenges of integrated food and energy production using videoed experiences and footage from the demonstration sites and existing farmer collaborators to provide real-world insights into potential outcomes. It will give farmers interested in pursuing the concept opportunities to discuss and explore the next steps they need to undertake.

Specific content could be wide ranging, potentially focusing on:

- Crops, energy crops and crop rotations
- Energy use and inputs on farms
- Use of agricultural bi-products and waste products, exploring the circular economy
- On-farm energy production and use, e.g.
  - Biogas
  - Biomass
  - Agrivoltatics
- Impact on carbon and greenhouse gas emissions
- Economic implications
- Experiences in different climatic regions of Europe
- Scale of activities and developments, for example farm, regional or country level

The OOC content will be delivered through a variety of media, for example including:

- Articles - bringing together information, may include case studies, research outcomes

- Discussions – opportunities to share experiences and discuss with other learners on the course
- Video or audio content – for example interviews with farmers from the V4F demonstration sites, researchers and agricultural advisors
- Assignments or Activities – could take a range of forms such as worked examples of (for example) a farm energy budget which learners can then undertake for themselves
- Quizes or questions - to prompt discussion or consolidate learning
- Links to research and resources – linking to freely available and open access resources will be a priority

The OOC will equip participating farmers and other learners with the knowledge and skills to start pursuing integrated food and energy production systems within their farm business. It will illustrate the practical benefits of these integrated systems through demonstration site experiences of a range of energy technologies. The OOC will also explore and expose farmers to the wide ranges of further groups, projects, organisations, literature, technologies relating to integrated food and energy production.

The FutureLearn platform ensures longevity of the OOC and provides opportunities to update and add new content and resources to the OOC if required. There is potential for the course to be accredited by EIT Food and then hosted on their Learning Services platform – this is to be explored.

3.4.2 Scenario based outputs from simulation platform

The agrivoltaic simulation platform developed by Amaducci et al., (2018) brings together a radiation and shading model with a crop growth simulator, enabling the varying levels of shading caused by the installation of photovoltaic panels and their impact on crop growth and yields to be explored. The platform can also be used to explore the impact of agrivoltaics on other variables such as crop irrigation. The platform was expanded by Agostini et al., (2021) to take economic factors into account.

The simulation platform conclusions and the environmental and economic impact assessments are based on current agrivoltaic installations within maize cropping systems in Northern Italy. Therefore, the data from Task 1.1 [and also WP3] will be used to develop a set of EU-wide scenarios that will be used to select a range of parameters for the agrivolatic simulation platform to provide case study outputs which will be presented to learners as part of the OOC. This will enable farmers in a range of situations to explore and consider how agrivoltaic systems could impact on their farm.

3.4.3 Audit tool

Within the framework of sustainability, where the social, economic and environmental pillars are involved, this audit tool will help to assess the potential energy assessment in the farm. Therefore social, economic and environmental indicators per farm will be assessed through a multicriteria analysis via a participatory development and use of innovative probabilistic Bayesian Belief Network (BBN) framework, used previously in EU Projects as in RECARE (Okpara et al. 2020). The indicators (social, economic and environmental) will be selected by literature review and together with the farmers (participatory approach).

The development of the decision tool enabling farmers to assess their farming system's potential for energy production will include the use of a SWOT analysis to see if integrated food and energy production does/should form part of the business objectives in the next 5 years. This could also explore the potential for change in business objectives. Where the SWOT identifies the possibility of a change to integrated energy in next 5 years a "digital" decision tree could be utilised in which a series of questions are posed about both the farm and farmers goals which then provides some form of overall suitability of integrated energy production and ranks in some way the prima facia best potential options for further exploration.

The audit tool may also comprise some questions to:

- Encourage reflection on crops and technologies suitable for integration into their business.
- Promote consideration of necessary changes within the farming system.
- Address the benefits and challenges associated with transitioning to integrated systems.

3.4.4 Transition tool

The Transition Tool will provide a comprehensive checklist of factors for farmers to consider before transitioning to integrated food and energy production. Based on the contents of the OOC and Audit Tool, the Transition Tool will enable farmers to consider how they might adapt their farms and adopt integrated food and energy production techniques and technologies.

In addition to the checklist the Transition Tool will bring together a range of tools, guidance and worked examples to support on-farm transition, for example:

- Worked examples based on models of financial impact
- Partial budgeting technique for estimating the financial impact of integration on the farm business.
- Guidance for practical facilitation of change and where to go to for support

Partial budgeting serves as a valuable decision support tool for farmers looking to assess the costs and benefits of integrating new activities, particularly renewable energy sources, into their farming systems. This approach provides a straightforward and practical way for farmers to analyze the financial impact of changes to their operations. With a focus on key aspects such as additional costs, savings, and potential income, partial budgeting helps farmers make informed decisions about adopting renewable energy solutions. By using this tool, farmers can weigh the expenses associated with implementing renewable energy sources against the expected returns, considering factors like reduced energy costs and potential income from selling excess energy back to the grid. In simple terms, partial budgeting empowers farmers to make well-informed choices, ensuring that the introduction of new activities aligns with their financial goals and sustainability objectives.

The Transition Tool will encourage farmers to take a systematic approach to the adoption of integrated systems. It will also direct end-users towards ongoing research and updates to keep the content relevant and up-to-date.

3.4.5 Learning Outcomes

The audit and transition tools will be embedded in the OOC, therefore the combined DSTs will provide a holistic learning opportunity for farmers. We have used the EIT Food Competency Framework (EIT Food, 2022) to map out the Learning Outcomes for the OOC. The key learning outcomes (LO) listed below are currently generically worded from the Competency Framework, but as the course is developed, the wording of these LOs will be adapted to make them more specific to the topic. We consider this course to be targeted at the EXPLORE level (laying the foundation in contributing to the food sector). The Primary competency in the Technical Capabilities is "Technology Management" and the Primary competency within the Underpinning Capabilities which our programme will teach is "Critical Thinking". This leads to the following key Learning Outcomes (table 16):

Table 16: Proposed learning outcomes for an Open Online Course.

LO1 (technology management)	Competently use appropriate technologies to contribute to food system innovations
LO2 (technology management)	Appraise the relevance of emerging technologies in a particular work or study context
LO3 (technology management)	Identify key unintended consequences of the use of emerging technologies
LO4 (technology management)	Recognise the importance of IPR management
LO5 (critical thinking)	Collect, analyse and report information and data to support the generation of new ideas and approaches
LO6 (critical thinking)	Recognise the importance of ethical goals.

4 CONCLUSION

The main objectives of T1.1. and T1.4 were:

Coordinate the creation of a farmer network: This has been achieved with active engagement with partners across the V4F network which provided a pool of over 4000 contacts from which survey responses and focus group participants were drawn, these were mainly farmers with interest in natural energy production associated with the various mailing lists of the partner organisations.

Review the literature on aspects of integrated energy and food production, cropping rotations and protocols and the use of DSTs on farms: Two largely separate reviews have been undertaken to help form a literature base for the project and to inform work in later work packages.

Design a questionnaire and focus group questions to explore farmers' knowledge needs: Both of these activities have been completed with 205 farmers and related stakeholders either responding to the survey or taking in part in one of the 5 focus groups.

The above activities have been utilised to *Develop a number of user stories and identify end-user needs:* These have been developed to underpin the V4F more generally in terms of farmer needs, to inform the 3 agricultural protocols (T2.2) and to inform the Decision Support Tool development (T1.4 & 4.5), and are summarised below

Key messages for V4F going forward:

Farmer needs in respect of integrated food and renewable energy production

Encouraging a Holistic Approach to Combining Food and Energy Production: Farmers could see the benefits of agrivoltaics to enable on-farm electricity generation and 58% of those surveyed had an interest in energy diversification. However, many see food production as a primary objective and thus careful consideration is needed to minimize yield reductions from agri-voltaic shading or to ensure the selection of a range of appropriate rotational crops that can enhance overall system sustainability as well as maintaining food production.

Biogas generation has a range of potential uses, including the potential to gradually replace the need for fossil fuels to provide rotary mechanisation which is a key barrier to achieving energy and sustainability on many farms. Some partners in V4F have demonstrated that with the right business case and appropriate legislation in place [ie BiogasDoneRight®] farmers can be successfully encouraged to adopt this form of energy generation. Some of the stakeholders in the focus groups had storage capacity and infrastructure concerns related to biogas production.

A key message for our V4F project is to consider if there are mechanisms that allow the farmer to "trial" adoption on smaller areas to demonstrate success and then to gradually scale over time. This is related to the context of whether the "system boundary" in terms of food/energy sustainability is viewed at the individual farm level which may be appropriate on some farms/regions, or whether the boundary relates to a number of farms in an area working in co-operation.

Sustainability Considerations: Various environmental factors need to be considered, such as the use of agrivoltaics reducing the need for irrigation and the impact of crop choices on energy use and production. It is clear that adopting appropriate crop rotations at a local level can balance food and energy production while supporting soil health. The opportunity for biogas production to make full use of waste streams or facilitate the use of a diversification of cropping for feedstock may also have additional environmental benefits. On-farm energy production was also seen as beneficial in terms of security [sustainability] of supply.

However, **a key message** for our V4F project is that the protocols and technologies being proposed will generally require a change to a given on-farm system, an investment in new technology, will require knowledge acquisition on behalf of the farmer and may, at least initially make their farm management operations more complicated. It is thus key that the project not only demonstrates improved environmental sustainability but that realistic and transparent financial cost modelling in relation to adoption can demonstrate a [substantial] financial benefit to a given farm business. This can be challenging as fluctuating energy and food prices, such as increasing energy prices, can influence the attractiveness [or not] of adoption.

Supporting the adoption process: It is clear from all elements of T1.1 that a range of financial incentives may encourage a wider farmer group to consider integrated food and energy production more seriously. These could include the availability of grants, low interest loans and financial recognition for environmental services provided. It was noted that national and regional legislation and planning [see D1.3 for overview] can impinge on farm practice and the potential for change, as can obstacles to injecting excess energy back into the grid. It was generally noted that more accurate information and knowledge concerning the energy generation opportunities, benefits and challenges were required [see DST section below] alongside working demonstrations which could be translated back into the "real" farm setting.

Considerations in relation to the proposed agricultural protocols

Crop Rotation and Energy Integration: Adapting crop rotations is highlighted as a method to maintain food/animal feed production while incorporating dedicated energy crops and utilizing crop wastes to support soil health. **A key message** for our V4F project is to keep rotational suggestions as flexible as possible and as closely aligned with existing knowledge in a given region. Introducing completely novel crops and rotations in addition to the expectation of the farmer to adopt new energy technology will heighten the adoption barrier.

Maximising the impact of the V4F demonstration and replication sites: Access to the regional V4F demonstration sites is required to expose farmers to possibilities and illustrate cropping protocols for successful integration of food and energy production. **A key message** for our V4F project is the importance of the demonstration and replication sites that are being established and that clear thought is needed to ensure as many farmers as possible are exposed to these. In person exposure is most preferable to end-users, but careful thought is needed about how a wider audience can be reached on a regular basis to "see" and experience the demo sites in operation, but also to ask questions in the context of operation of their own farming systems particularly in relation to set up issues/costs and crop protocols.

Decision Support Tool Development

Understanding and supporting motivations: The survey respondents indicated that 58% were considering investing in energy diversification on their farms in the next five years. **A key message** is that the DSTs will need to start from the two key declared motivations for this investment as; improving farm profits and improving the sustainability of the business. This high level of interest was coupled with a clear need for financial support, confidence that it would provide a good financial return, support with understanding legislation and permits, and the provision of information and expertise. These key topics will need to be covered in the three-part Value4Farm decision support tools which are being developed to meet the identified gap in provision of tools/educational courses that consider the integration of both energy and food production from agricultural land in Europe. The understanding of farmers' knowledge needs gained from the survey and focus groups will ensure that the tools are of most use to the target group of end-users (farmers and their advisors). This meets the first criteria of "relevance" on Rose et al.'s (2016) checklist for increased adoption of DSTs.

Developing the right decision support tools: The focus groups provided the details behind the current knowledge needs and highlighted that information and support tools need to be developed to support two future pathways to adoption; one where farmers adopt technologies that can support on-farm circular systems (self-sufficiency) and one where farmers integrate into larger infrastructure projects. There was also clear preference for peer-to-peer, specialised and experiential learning models (i.e. workshops, demonstrations) and online, video materials. The framework outlined in Section 3 illustrates how the co-design inputs from farmers will inform the tool development and will adhere to Rose et al.'s (2016) other criteria of "ease of use", "trust" and "habit". Linking to the **key message** above relating to access to the demonstration sites, the DSTs will need to incorporate access to these practical, on-site knowledge exchange experiences and provide interactive elements within a holistic and evidence-based educational package.

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6 APPENDICES

Appendix 1: Literature reviews

6.1 Energy Use and Production in European Agriculture

Across the European Union (EU) agriculture and forestry accounted for 3.2% of direct energy consumption in 2020, the majority (56%) of this was from oil and petroleum products. Between 2000 and 2020 the direct consumption of energy in the EU from renewables and biofuels more than doubled, a pattern followed in the agricultural and forestry sector with approximately 11% of the energy consumed in 2020 coming from renewable or biofuel sources (Eurostat Energy Use, 2022)

Energy is used in wide range of settings, from diesel consumption in farm machinery to the electricity used to heat and power greenhouses and irrigation systems, The energy for these systems could come from a variety of sources, including heat pumps, wind turbines, solar panels, fossil fuels [mainly diesel, petrol and gas], biomass and biogas.

Farming can produce energy in a variety of ways:

- Growing crops for biomass – annual and perennial crops
- Using crop waste for biomass, e.g. straw, plant husks /stems
- Using crop waste (in the form of e.g. slurry) to produce biogas and / or energy on site or for use off-farm
- Using other farm waste – tree, hedge trimmings for biomass
- Producing renewable energy (e.g. solar panels or wind turbines) on a variety of land types
    - Land unsuitable for crops
    - Land unsuitable for crops, but can be combined with livestock
    - Combining e.g. solar panels and crops – agrivoltaics
    - Solar panels (e.g.) on farm / agricultural buildings – greenhouses, dairies, livestock sheds

Producing energy crops or generating energy on the farm can benefit farms in a variety of ways:

- Additional income streams from selling electricity, heat or power
- Reducing energy buy-in from the national grid / network
- Encourage crop rotations – combining food, fodder and energy crops in mixed rotations can:
    - Improve soil and soil function – e.g. texture, N content
    - Help to reduce pest / disease spread and potentially reduce pesticide use
    - Improve crop diversity and biodiversity
- Reduce waste disposal requirements
- Potential for byproducts of energy production to be used (e.g. animal fodder)

This review will consider the current use and potential use of energy generation in agricultural settings across Europe. It will explore the benefits and barriers to growing energy crops and producing energy both on and off-farm using a variety of methods. It will also look at the information and knowledge sharing available to farmers to help them explore the opportunities to generate energy and how this may benefit their farm. In particular the decision support tools and systems available to farmers to help them explore and monitor crops and energy use and production on their farm will be considered.

6.1.1 Crops and Crop Production

Across the European Union (EU) a diverse range of crops are grown commercially. Crop production is focussed around arable crops, predominantly cereals (such as wheat, barley and oats), with root crops and oilseeds also making up a large proportion of crop production (Eurostat crops, 2022). Other crops grown across the EU include vegetables (tomatoes, carrots, onions, brassicas, leafy vegetables), pulses (field peas, broad beans), grapes, olives, fruits, fibre crops (flax, hemp), industrial crops and energy crops.

In 2020 approximately 157 million hectares of land in the EU was used for agricultural production, with arable land accounting for 62% of agricultural land use and permanent grassland and meadow a further 31%. Of the crops grown on arable land, cereals occupied 54%, fodder crops 21% and industrial and other crops (including biofuels) around 25% (Eurostat cropping patterns, 2023). Figure A1 shows the breakdown of crop production across the EU from 2018 to 2022, Figure A2 highlights crop production in Belgium, Denmark, Iceland, Italy, Netherlands and Poland across the same time period.

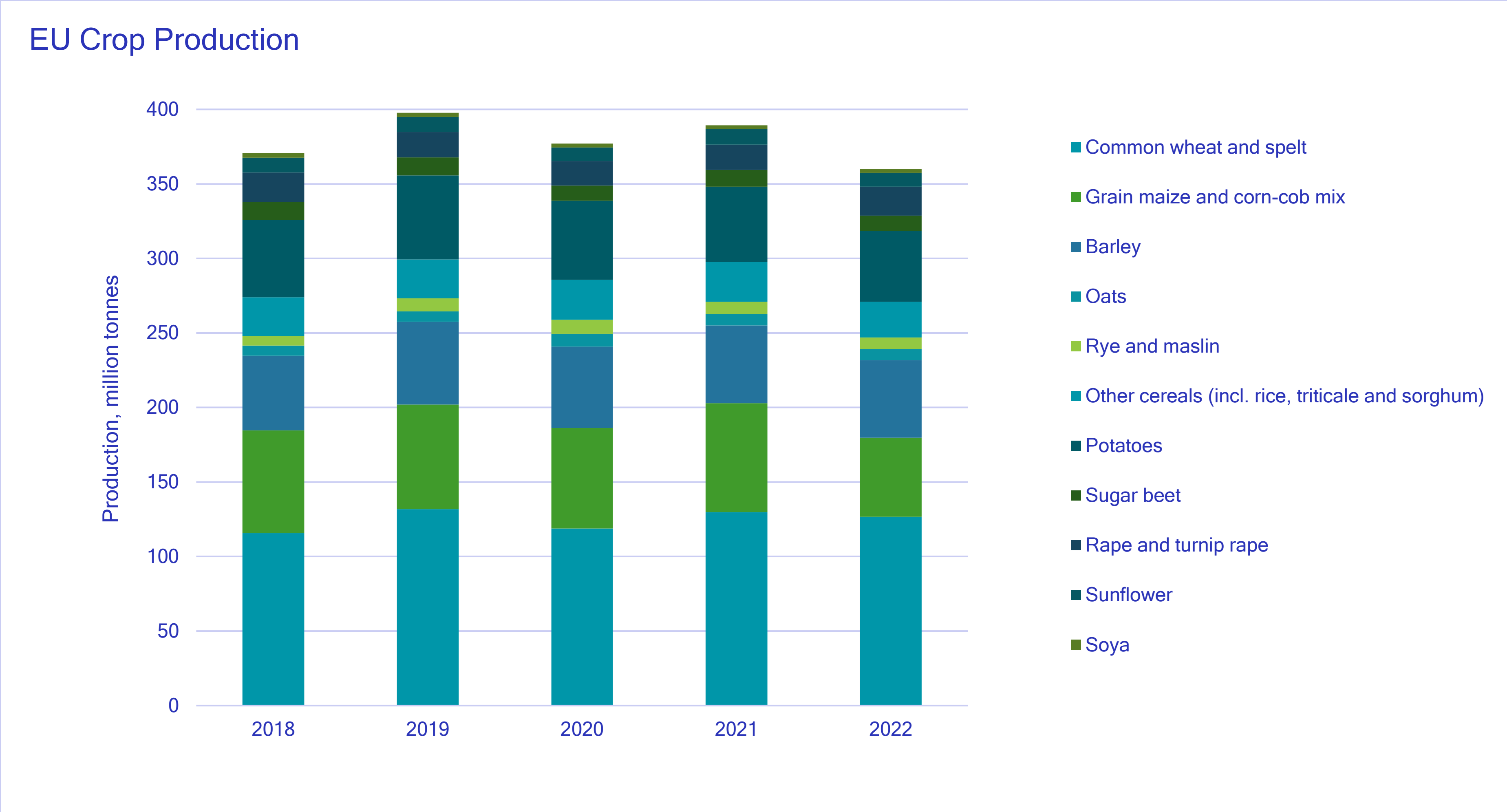
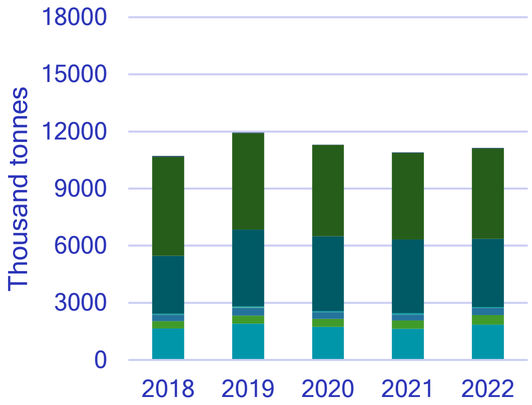
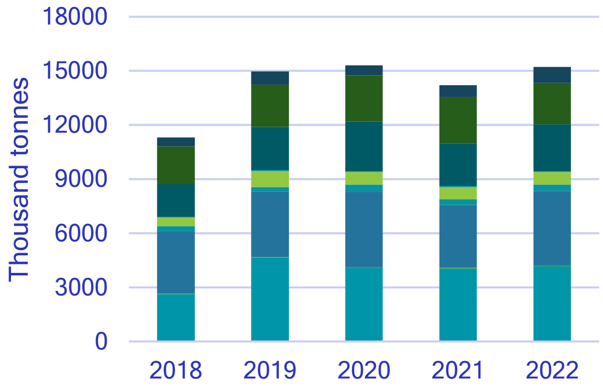


Figure A1: Breakdown of main cereal, root crop and oilseed crop production (million tonnes) from 2018 - 2022 in the EU, with 2018 - 19 including the EU28, and 2020 - 22 including the EU27 following the UK leaving the EU. Data from Crop production in EU standard humidity dataset (Statistics | Eurostat (europa.eu)).

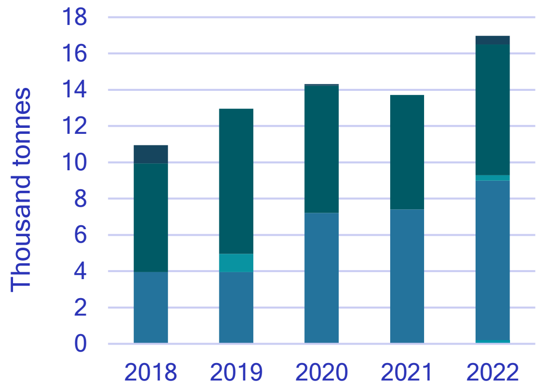
Belgium



Denmark



Iceland



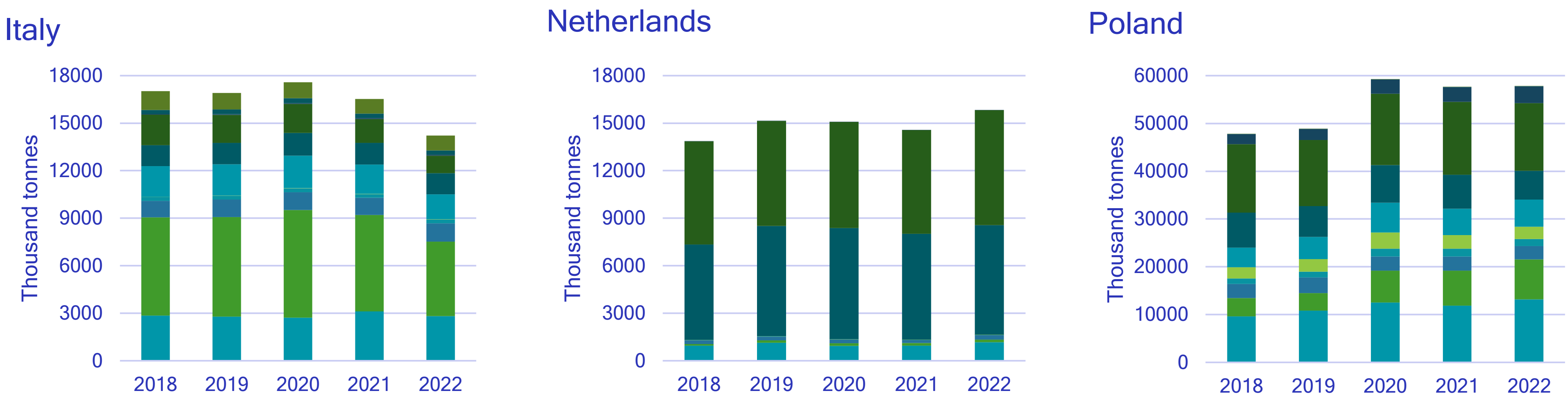


Figure A 2: Breakdown of main cereal, root crop and oilseed crop production (thousand tonnes) from 2018 - 2022 of Belgium, Denmark, Iceland, Italy, Netherlands and Poland. Note differing scales for production in Iceland and Poland, key shown with figure 1. Data from Crop production in EU standard humidity dataset (Eurostat Database, 2023).

The majority of cereal crops grown in the EU are for human consumption or livestock feed / fodder provision. Data from 2020 (Eurostat Key Figures, 2022) indicated that the majority of cereals consumed in the EU (54%) were used for animal feed, 28% for human consumption, around 10% for industrial uses (not including biofuels), 4% for seed and approximately 3% for biofuels.

Across the EU, 395 thousand tonnes of energy crops were produced in 2017 (Eurostat Database, 2023), Figure A3 gives a breakdown of the countries where energy crop production was recorded. The figures for energy crop production are less well recorded than those for other crop types. The figure of 395 thousand tonnes refers to crops produced solely for the purposes of energy generation. It does not include crops, for example, grown for food where bi-products or waste products are used to generate energy and includes only crops grown on arable land. For the majority of countries the figure for energy crop production was recorded as “0” or no values were given. A number of countries (Denmark, France, Iceland, Norway, Slovenia, Sweden and Switzerland) recorded “not significant” energy crop production, implying that there was production but at very low levels.

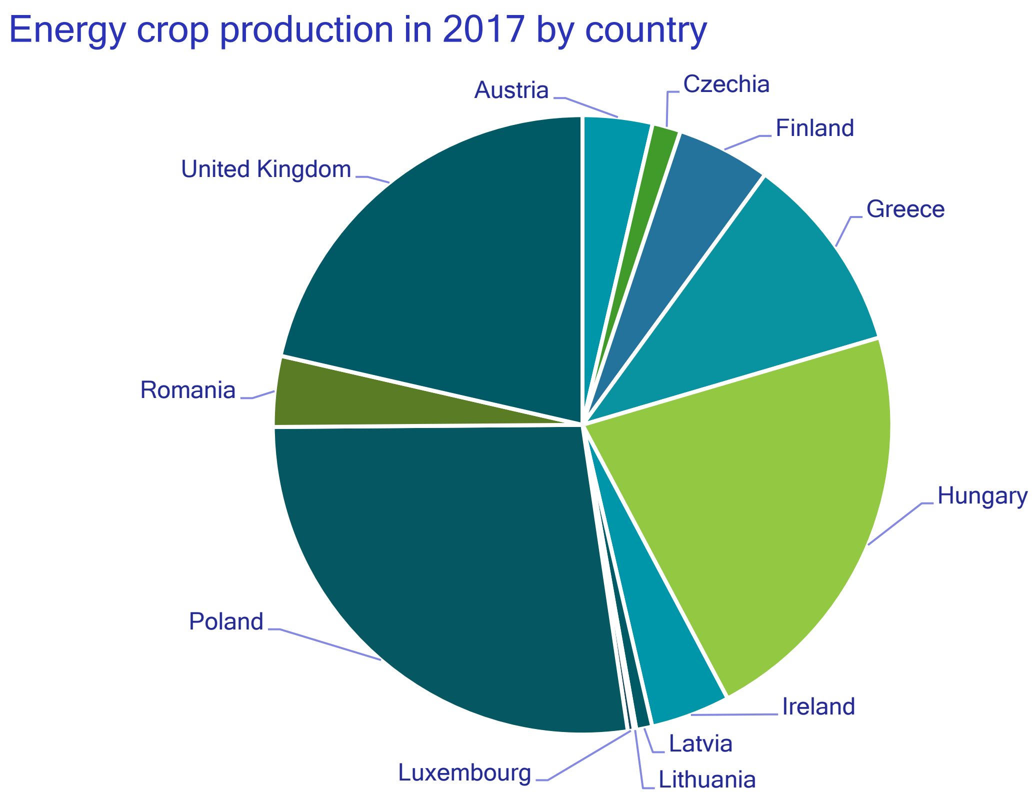


Figure A3: Energy crop production in 2017 by country. Note that the UK was still part of the EU in 2017, from Eurostat Database (2023)

Between 2018 and 2022 an overall / total figure for energy crop production was not given, however, figures for energy crop production were recorded for six countries: Austria, Czechia, Greece, Hungary, Ireland and Romania (Eurostat Database, 2023). These are presented in Figure A4.

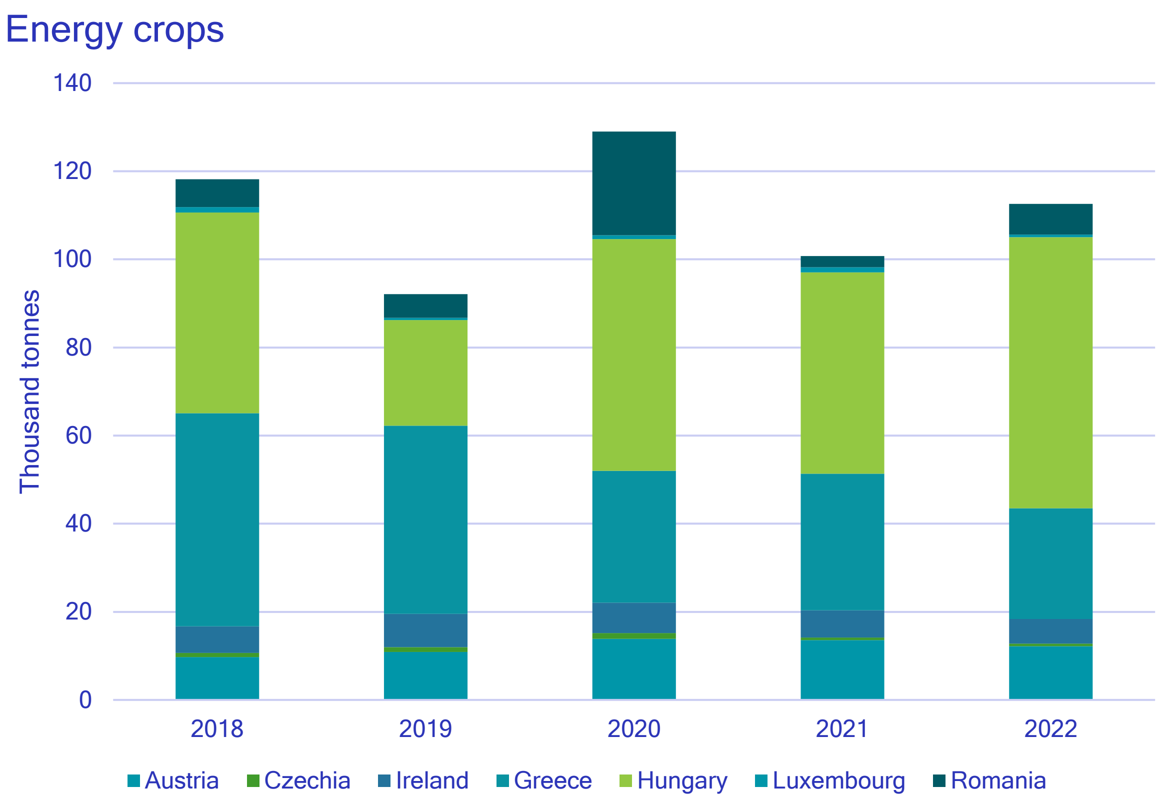


Figure A4: Energy crop production by country 2018 - 2022 (Eurostat Database, 2023).

6.1.2 Energy crops

Energy crops are typically high yield crops which can be densely planted in order to provide high outputs. Ideally, they have high photosynthetic efficiency and low fertiliser requirements. Crops grown for the purposes of energy production can be wide-ranging and generate energy in a variety of ways. The following definitions are taken from the UN's International Recommendations for Energy Statistics (United Nations, 2017):

- Biofuels: Fuels derived directly or indirectly from biomass.
- Solid biofuels: Including fuelwood, wood residues and by-products, wood pellets, animal waste, black liquor (liquor obtained during paper manufacture) and other vegetal material and residues (including straw, vegetable husks, pruning brushwood, and other wastes from maintenance, cropping and processing of plants)
- Liquid biofuels: Liquids derived from biomass and used as fuels, including biogasoline (e.g. bioethanol and biomethanol) and biodiesels. They may be used for transport, electricity generation or stationary engines.
- Biogases: Gases arising from the anaerobic fermentation of biomass and the gasification of solid biomass (including biomass in wastes). Biogases can include landfill gas, sewage sludge gas and biogases from anaerobic fermentation. Two of the largest sources of biogases from anaerobic fermentation are the fermentation of energy crops and the fermentation of manure on farm

The crops grown to generate biofuels can be wide-ranging, for example oilseed crops producing the precursor for biodiesel production, starch and sugar crops produce the material for bioethanol production and short rotation coppice such as willow or poplar for the production of wood pellets.

Table A1 gives a breakdown of the range of energy crops grown in the EU and their potential uses. Forest Research (2024) give the following example of how wheat can provide a range of bioenergy: "*Very high outputs per hectare can be achieved from energy crops such as wheat, which typically yields 7.5-8 tonnes of grain per ha in the UK, in addition to which there is typically 3.5-5 tonnes per ha of straw. The grain could be used to produce liquid transport fuels and the straw could be burned to produce heat or electricity.*"

Table A1: Example energy crops grown in Europe, from Vera et al (2021), European Biomass Association (https://www.eubia.org/cms/wiki-biomass/energy-crops/), Defra (2020) and Forest Research (2024).

Type	Species	Potential uses
Perennial	Miscanthus	Biomass
	Switchgrass	Biomass
	Giant reed	Biomass
	Reed canary grass	Biomass
	Tall Fescue	Biomass
Short Rotation Coppice (SRC)	Willow	Biomass
	Poplar	Biomass
	Eucalyptus	Biomass
Annual	Wheat	Bioethanol - Grain
		Biomass - Straw
	Oilseed rape	Biodiesel
		Biogas
	Sunflower	Biodiesel
	Barley	Bioethanol - Grain
		Biomass - Straw
	Maize	Biogas
	Sugar beet	Bioethanol
		Biogas
	Soybean	Biodiesel
	Sweet sorghum	Bioethanol
	Hemp	Biomass

Amon et al., (2007) explored the energy production potential from a range of crops grown in Austria, both biomass and methane production were considered, the crops grown were: maize, wheat, sunflower, rye, triticale and grass (permanent grassland). Maize and cereals gave good methane yields, and they provide recommendations / guidance on achieving the best methane yields from these crops, including considering which varieties to plant and when best to harvest to give maximum yields.

Land-use may also be an important consideration. Is there potential for some energy crops to be grown on marginal land which may not be suitable for food or fodder crops? Vera et al., (2021) note that "*Smart choices on location, crop type and supply chain design are paramount to achieve maximum benefits of bioenergy systems*."

6.1.3 Limitations

Restrictions or limits may be placed on the area of land used to grow energy crops, or the proportion of crops grown specifically for energy generation, in order to ensure food and feed production is maintained and potentially to encourage the use of waste or bi-products in generating energy.

For example, RED II (the Renewable Energy – Recast to 2030 initiative from the EU) while aiming to increase renewable energy consumption across the EU, also places some restrictions on changing of land use to growing energy crops and a limit on the final consumption of bioenergy in the road and rail transport of individual member states of 7% (EU Science Hub, 2023).

Restrictions put into place in Denmark in 2018 limited the amount of purpose-grown energy crops used in biogas generation in biogas plants receiving state aid to 25% of their total feedstock, with further reductions in 2018 to 12% of the total (New limitations on energy crops use for biogas in Denmark | European Biogas Association). Also noted were limitations put in place in both France and Germany on the use of purpose-grown energy crops for producing biogas, with the aim of increasing the use of agricultural wastes in biogas production.

The potential for bi-products or waste products of food and fodder crops to be used in the production of biofuels should also be considered. For example, grain has been grown for food or feed, the straw and husks could be used to produce biogas. It should also be noted that the bi-products of crops grown to produce bio-energy may themselves be useful as e.g. livestock feed (Gaffey et al., 2023).

6.1.4 Crop rotations

Crop rotation, the practice of alternating the crops grown in a set sequence so crops of the same species are not grown without interruption on the same field, can support a range of agricultural and ecological benefits. Rotations can help to break crop disease and pest cycles, increase crop diversity and improve yields. Cover crops used during rotations can help to reduce soil erosion and improve water quality by reducing run-off and the classic example of including legumes in rotations supports nitrogen fixation and can reduce the need for fertiliser use.

Rose et al., (2023) trial modified crop rotations in order to reduce nitrate groundwater contamination, reduce N fertilisation requirements and increase yields. Rotations were changed to follow crops with typically high mineral nitrogen with autumnal crops with high N uptake (e.g. winter oilseed rape and catch crops).

Costa et al., (2021), modified crop rotations in Italy, Romania and Scotland to include legumes. Legume modified rotations required less fertiliser input, had enhanced yields in crops following legumes and output had an improved nutritional profile. Voisin et al., (2014) also explore the potential for legumes in rotations and intercropping and for the production of food, fodder and bioenergy. The also consider nitrogen fixation and the role of legumes as "service plants", "*Service plants are defined as unharvested co-crops, producing a service to a main crop or rotation. The expected services are a better weed control and a better management of nitrogen fertilisation*"

Garland et al (2021) consider the benefits of cover crops as part of rotations, where cover crops could support increased crop diversity and benefit the soil structure and microbiome. Cover crops have also been suggested as potential sources of bioenergy or biomass. Jacobs et al., (2016) compare inputs and yields of three crops: Sugar Beet (SB) and Silage Maize (SM) grown for biogas production and Winter Wheat (WW) grown for food. "*The net-energy yield and land demand values presented are among the largest and the lowest, respectively, for rainfed*

Central European conditions. As the preceding crops, SB induced a higher energy performance of the subsequent WW than SM. When taking such crop rotation effects into account for the overall evaluation, we concluded that SB root as a biomass crop is a suitable alternative to SM" and *"The energy performance was found to be highest for silage maize. However, sugar beet root showed in some cases only slight differences from silage maize. Hereby, we found that sugar beet had a positive effect on the energy performance of the subsequent crop in the rotation."*

6.1.5 Biomass rotations and byi-products

Figure A5 highlights some of the routes for the conversion of biomass to energy, considering both energy crops and the byproducts of food / fodder crops and other agricultural wastes.

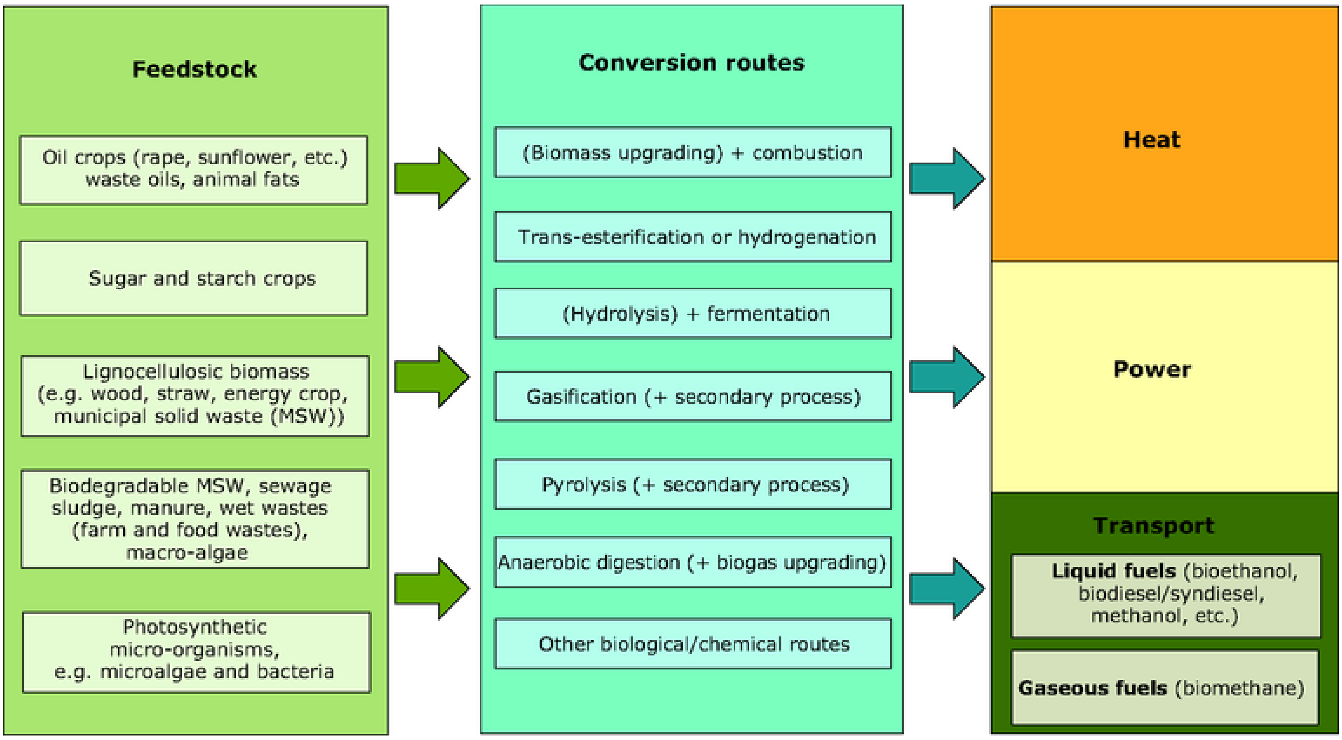


Figure A5: Routes for converting biomass to energy. Routes for converting biomass to energy – European Environment Agency (europa.eu)

Integrated crop rotations can bring together multiple crop types in order to produce food, feed, raw materials and energy, they may also include cover crops which could be used for energy generation.

Amon et al., (2007) give an example of a sustainable crop rotation used in Austria, integrating food, feed and energy production: Maize (whole crop silage) > Winter wheat (straw) > Intercrop (clover grass) > Summer barley (straw) > Sugar beet (leaves and pressed beet pulp silage) > Sunflower (whole crop silage) > Intercrop (lucerne).

Manevski et al., (2017) describe two different rotations used in Denmark, optimised rotations for high yields of a range of crops some of which are used for energy production.

- Rotation 1 – 4 year rotation incorporating: maize, beet, hemp, triticale and grass/clover and winter rye as cover crops between the major crops
- Rotation 2 – 3 year rotation incorporating: maize, winter rye, winter rapeseed as a cover crop and hemp

Jacobs et al., (2016) included silage maize and sugar beet, for biomass production, in crop rotations and assessed the energy production of both. Silage maize was found to have a slightly higher energy performance than sugar beet, but sugar beet had a positive impact on the energy performance of the next crop in the rotation. They concluded that "*sugar beet root as a biomass crop is an alternative to silage maize especially in crop rotations on highly productive sites*".

Molinuevo-Salces et al., (2013) looked at the potential for different catch crops to be integrated into rotations in order to provide feedstock for biogas production. Catch crops were viewed as a byproduct that could be used for bioenergy production, and while they were part of a rotation they would not interfere with the production of food and fodder crops.

Amon et al., (2007) suggest a number of strategies to support integrated crop rotations including:

- Food to non-food switches – alternating crops for food, feed, raw materials and energy production.
- Using different parts of the same crop for different aspects of energy production, for example, starch from maize corns and biogas from the remaining maize plant.
- Having mixed cultivation of several energy crops: e.g. sunflower and maize.

When developing high biomass rotations, there are a number of considerations regarding the conventional and energy crops to be included, such as local conditions (soil types, rainfall, radiation), yields and the prices paid for food, feed and energy crops (Knapek et al., 2021; Manevski et al., 2017). Energy balances also need to be taken into account, some crops have high energy inputs, for example requiring more input in the form of fertiliser, fuel consumption in harvesting or increased irrigation which can require energy inputs in the form of fossil fuels. Table A2 brings together some example figures for the indirect and direct energy consumption of a range of annual and perennial crops. The table highlights the higher energy inputs of some crops, which may lead to higher yields per hectare, however it is also relevant to consider the type of output and the changing costs of inputs and changing prices for outputs.

Table A2: The energy balances of a range of annual and perennial crops, adapted from Cropgen (2006). Indirect energy requirements include the energy used in the construction and delivery of products used in crop production (e.g. fertilisers). Fuel use may include use for ploughing, sowing and harvesting. The values given for annual crops assume that crops are grown under the same conditions and are fertilised at the recommended rates with mineral-based fertilisers. For perennial crops year 1 is the sowing year.

	Crop	Energy requirements (GJ/ha)				Yield (tFM/ha)
		Indirect	Fuel (l/ha)	Fertiliser and sprays	Total	
Annual	Maize	1.92	2.78 (71)	11.8	16.7	40
	Wheat	1.84	2.26 (57)	12.7	17.0	36.5
	Fodder Beet	3.76	3.38 (86)	14.4	21.8	80
	Triticale	1.84	2.26 (57)	11.6	16.0	38
	Sunflower	1.85	2.26 (57)	10.9	15.3	35 (est.)
	Lupin	1.81	2.20 (56)	4.3	8.6	30 (est.)
	Field Bean	1.64	2.05 (52)	3.83	7.8	35 (est.)
Perennial	Ryegrass year 1	2.4	2.62 (67)	12.1	17.7	33
	Ryegrass yrs 2 and 3	4.2	4.62 (117)	12.1	21.1	42
	Clover yr 1	2.1	2.37 (60)	7.3	12.3	42
	Clover yr 2	2.3	2.59 (66)	7.3	12.2	40

6.1.6 Bi-products

While dedicated energy crops can form part of mixed rotations, bi-products or waste from food and fodder crops can also form an important part of energy generation. Gaffey et al., (2023), review various aspects of biogas production and the biorefining process, and highlight the potential for bi-products and waste feedstocks to be used in addition to dedicated biomass / feedstocks. They note that waste or bi-products “can offer significant benefits for Green Biorefineries including continuity of supply chain during certain unproductive months (e.g., when fresh grass will not be available), a low-cost opportunity to valorise waste streams, and the opportunity to reduce the overall environmental footprint of the model through inclusion of by-products and wastes.”

There is also the potential for the remnants of energy production to be used on-farm – a circular economy, for example Molinuevo-Salces et al., (2013) highlighted how the digested effluent from biogas production can be used as fertiliser, Mujtaba et al (2023) review the wide range of potential uses of lignocelulosic waste from energy crops and forestry wastes, including biofuels, bioplastics, biocomposites (e.g. biochar for environmental remediation), 3D printing “inks”, biomedical applications (cellulose, lignin, and hemicellulose for medicinal purposes and drug applications) and chemical production as an alternative to using petroleum. They conclude that agricultural wastes could play a role in reducing the use of fossil fuels and petroleum-based products in a range of industries and support a circular economy.

6.1.7 Biogas

Through the process of anaerobic digestion organic matter can be converted into biogas, a methane rich gas which can be used to generate heat and electricity or used as biofuel. The process also produces digestate which can be used as soil improver . Anaerobic digestion can use a range of organic matter as feedstock (for example livestock, crop and food waste and dedicated energy crops) to produce energy. Figure A6 illustrates the inputs, process and outputs of anaerobic digestion.

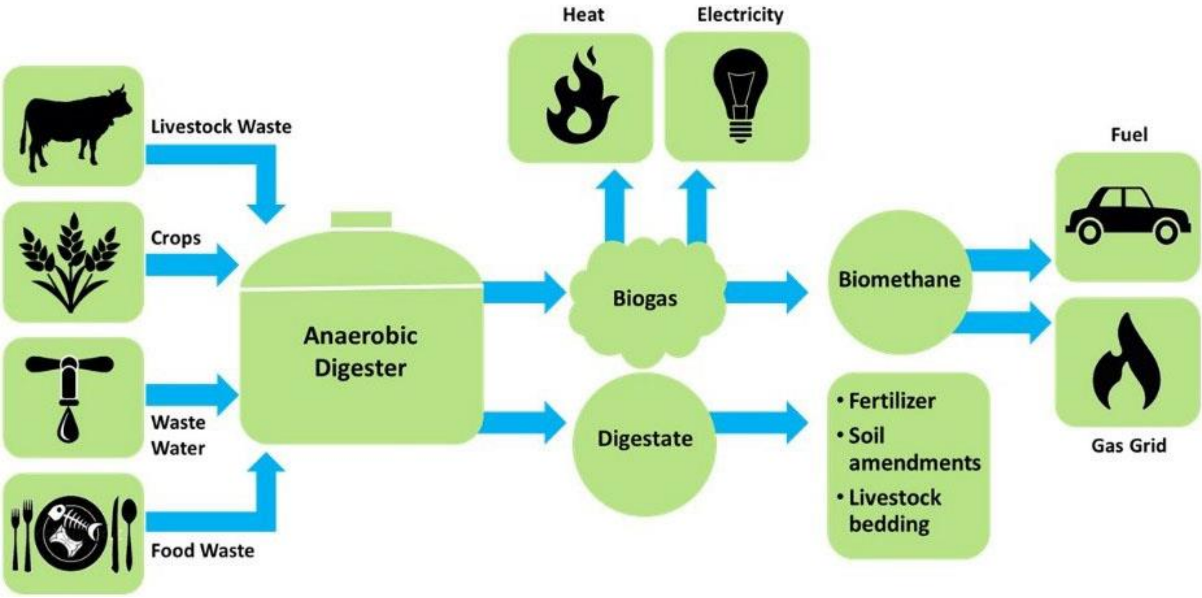


Figure A6: Biogas production, uses and bi-products. From: Fact Sheet | Biogas: Converting Waste to Energy | White Papers | EESI

Biogas production can be undertaken at different scales, for example using small farm-based digesters, utilising farm wastes and producing energy for use on or off-farm, or larger municipal digesters taking in feedstock from a wider range of producers (e.g. industrial food waste in addition to farm waste) and producing energy to feed into the national power grid. Large scale digesters could take in a more extensive range of wastes as feedstocks (for example waste originally headed for landfill) and supply more energy to the national electricity grid. However, there will be increased travel distances to get feedstock to the plant, increasing greenhouse gas emissions, and they may face local opposition or issues around planning permission.

Smaller, farm-based digestors may take a mixture of feedstocks from a single farm and potentially other local farms. Feedstock could be dedicated energy crops, crop bi-products, crop and livestock waste (e.g. slurry), and may produce energy to be used on-farm or feed into a national grid. These farm-based digestors will have low transport distances and could reduce the need for farm waste disposal. However, they could face local opposition to building and running digestors and there may be less local expertise available to run and maintain digesters.

The BiogasDoneRight™ initiative brought together a group of Italian farmers in 2008 in order to use farm-based anaerobic digestors to produce biogas which would then be burned on-site to generate electricity for the national grid. Farmers involved in the initiative changed their practices, for example introducing double cropping, the first crop was grown for food / feed and the second crop (such as winter rye, triticale, forage wheat, or corn silage) was grown for the digesters, to enable the digesters to operate throughout the year. Digesters were also fed manure and other wastes and bi-products, for example feed crops that did not meet required standards (Dale et al., 2016).

A range of crop wastes, bi-products and dedicated energy crops can be used as feedstock in producing biogas. This may depend on region, climate and farm topography, Markou et al (2017) suggest that the selection of an appropriate crop for biogas production should be based on the crop digestibility (methane yield) and biomass yield per hectare. Table A3, adapted from Markou et al., (2017) gives the dry mass and methane yields from a range of crops grown across four locations in Europe and illustrates the changing dry matter and methane yields of a range of crops.

*Table A3: Dry matter and methane yields from a range of crops grown in four different countries. Adapted from Markou et al, (2017). * Methane yield per kg of volatile solids ** Methane yield per tonne dry matter*

Country	Crop silage	Dry mass yield (t DM/ha)	Specific Methane yield
Austria	Maize	14	340 m3N /kg VS*
	Millet	12	317
	Sugar beet	14	377
	Wheat	10	292
	Sunflower	10	275
	Rye	7	332
Sweden	Triticale	9	380 m 3N /t DM**
	Sugar beet top	-	300
	Maize	10	350
	Ley	10	300
	Hemp	10	250
Italy	Triticale	17	372
	Maize	22	382
	Grass	11	317
	Sorghum	19	233
	Rye	9	306
Greece	Triticale	14	320
	Maize	16	330
	Alfalfa	9	280
	Sunflower	11	290
	Clover	7	320
	Barley	5	300
	Wheat	5	310

It may be important to consider in growing feedstock or using a combination of wastes, bi-products and dedicated energy crops:

- The methane yield of crops or wastes used

- What grows well in the region or on the farm, high methane yield species may not be ideal crops for a particular location, requiring more space, fertilisers, irrigation etc. For example, Markou et al., 2017 note the high methane yield of maize and also highlight the low methane yields of wheat and barley, leading to increased land use for production to produce equivalent volumes of methane, which would be unsuitable in Greece where land availability is low
- Using cover crops or wastes as feedstock rather than a dedicated energy crop can mean food / feed production is maintained
- Crop energy balances - the input required to grow, harvest and transport the crop or feedstock compared to the energy it can produce.

Dale et al., (2016) also highlight that "*Producing bioenergy and/or environmental services may render land that is uneconomical for food production sufficiently profitable to change marginal land into useful land. For example, perennial grasses planted on poor soils or sloping terrains may fix carbon in the soil and reduce erosion while still harvesting the grasses for animal feed and bioenergy production. Arid lands unsuitable for food crop production can be planted with low water use plants to provide animal forages and bioenergy*."

6.1.8 Where is energy used in farming and agriculture?

Across the European Union (EU) agriculture and forestry accounted for 3.2% of direct energy consumption in 2020, the majority (56%) of this was from oil and petroleum products. Between 2000 and 2020 the direct consumption of energy in the EU from renewables and biofuels more than doubled, a pattern followed in the agricultural and forestry sector with approximately 11% of the energy consumed in 2020 coming from renewable or biofuel sources (Eurostat, 2022)

Energy use can be divided into direct and indirect use. Direct use is energy used on-farm and up to the farm gate, this would include energy consumed by (for example) on-farm transportation, heating, cooling, lighting and irrigation, machinery, farm management and automation (Paris et al., 2022b). Indirect use is energy used in the production of agricultural inputs, energy used by the agricultural sector prior to reaching farms, for example in the manufacture and transport of seeds, fertilisers and pesticides. (Paris et al, 2022b). The largest consumption of energy in EU agriculture is the production of fertiliser, which accounts for approximately 50% of all energy inputs (Paris et al., 2022b)

Energy use will depend on range of factors, such as crops grown and farm location. For example, the highest energy use in the agricultural and forestry sector across the EU is in the Netherlands, accounting for 9% of the direct energy use. This reflects the important role of glasshouse production of fruit, vegetables and horticultural plants in the Netherlands (Eurostat, 2022). Paris et al., (2022a) reflect on the differences between northern and southern Europe; "*High energy systems, which are more dominant in northern Europe, are generally heavily climate controlled and energy use is dominated by heating and cooling processes, while low energy systems, which are dominant in southern Europe, show a mixture of energy uses including heating, cooling, irrigation, lighting, fertilisers, and pesticides.*"

Energy for these systems could come from a variety of sources, including heat pumps, natural gas, wind turbines, solar panels, fossil fuels, biomass and biogas. In their review of energy use in greenhouse systems across Europe, Paris et al. (2022a) highlight a range of ways to improve energy efficiency and reduce the use of fossil fuels in maintaining greenhouse crop growing, including the use of solar technologies, specifically those integrated with the greenhouse system (agrivoltaics) and the use of biogas and bioenergy to generate electricity.

In open-field agriculture, Paris et al., (2022b) found that approximately 8% of open-field agriculture was powered by electricity (often for irrigation, storage and drying purposes) and suggest that switching to electricity-powered systems and moving towards renewable energy sources in generating electricity, such as solar or biogas, could significantly reduce fossil fuel use on farm.

6.1.9 Energy production

As highlighted above, the production of biogas from either purpose grown energy crops or agricultural waste or bi-products can be used to generate energy on or off-farm. Other methods include using geothermal sources, wind turbines or agrivoltaics.

6.1.10 Agrivoltaics

Agrivoltaics generally refers to the simultaneous use of land for both solar photovoltaic power generation and agriculture in some form of combination. Photovoltaic panels are mounted at a height from the ground that enables conventional cultivation practices underneath, meaning photovoltaic panels can be installed without competing directly with agricultural land (Agostini et al, 2021). This leads to the potential for more efficient land use, areas can be used to grow crops, house livestock and generate electricity. As agricultural activities can continue, land can also remain eligible for agricultural subsidies under the Common Agricultural Policy (CAP) (Chatzipanagi et al, 2023). Agrivoltaics could also include solar panels mounted on agricultural buildings.

Toledo and Scognamiglio (2021) review agrivoltaic systems designed to fit with a range of farming types, for example high mounted to allow agricultural equipment access, low mounted to provide shade and tracking systems to improve solar energy capture. A study by Agostini et al (2021) found that around 80 – 90% of the land under agrivoltaic systems could still be cultivated using common agricultural equipment and standard practices. The steel mounting rods could reduce accessibility but this land could be turned over to alternative horticultural crops or livestock that did not require large agricultural machinery. Photovoltaic panels could also be installed as a fence or hedge, marking field boundaries, containing livestock and generating power (Masna et al., 2023) whilst still enabling crops to be grown and having less impact on accessibility for agricultural equipment.

With respect to tracking or dynamic systems, a study by Valle et al., (2017) noted: "*very high productivity per land area unit could be reached using dynamic instead of stationary photovoltaic panels in agrivoltaic systems while maintaining a biomass production of lettuce at levels close to or even similar to that in full-sun conditions*.". Figure A7 shows some examples of fixed and tracking agrivoltaic systems, illustrating the different ways in which photovoltaic panels can be mounted to enable cultivation and machinery access.

Figure A7: Example agrivoltaic arrays, from Toledo and Scognamiglio (2021)

6.1.11 Energy outputs

What would be the estimated / expected / actual outputs from agrivoltaic systems? Agostini et al., (2021) highlights that "*When compared to a biogas system fed with maize cultivated in the same area [Po Valley, Italy], the PV systems produce 20–70 times more energy per square metre*". Outputs will vary according to a range of factors, such as the density of photovoltaic panel placement (Valle et al., 2017), panel orientation (Trommsdorf et al., 2021) and tracking ability and climatic conditions (Ammaducci et al., 2018), Table A4 presents some example outputs of agrivoltaic systems.

Table A4: Example power outputs of a range of agrivoltaic systems

Location	PV set-up	Power output kWh.m^{-2}	Study
Italy, Po Valley	Tracking, lower density, field based	17.4	Amaducci et al., 2018
	Static, lower density	11.7	
	Tracking, higher density	64	
	Static, higher density	43.4	
France, Montpellier	Static, lower density, field-based	8.5	Valle et al., 2017
	Tracking, field-based	13	
	Controlled (restricted) tracking, field based	8.3	
	Static, higher density, field based	16	
Italy, Sardinia	Static, greenhouse-based	11	Cossu et al., 2023

6.1.12 Potential impacts of agrivoltaics

In addition to generating income for the farm business and / or reducing energy bills on the farm from electricity generation, agrivoltaics could have a range of impacts on farms and crop production. Agrivoltaics, whilst they can be combined with crops could also be suitable for less productive areas of farmland and may provide additional farm income through "renting" land for solar panels.

However, installing agrivoltaics could lead to soil compaction and loss of land for food production. Farm topography and location / positioning of photo voltaic panels will impact on solar energy and energy production, Bao et al, (2023), Feuerbacher et al., (2022) and social acceptance, from both farmers and the general public may not be forthcoming (Torma and Aschemann-Witzel, 2023).

Also there is a need to consider that there may be variable legal definitions relating to agrivoltaics and requirements for their size, density or placement depending on country. Chatzipanagi et al., (2023) explore some of the differing definitions of what agrivoltaics are, and the rules relating to e.g. placement of agrivoltaics. More on the legislation will be covered in Deliverable 1.3.

6.1.13 Crop shading and sheltering

The shading effect of photovoltaic panels can reduce evapotranspiration from crops, reducing water use and irrigation needs, and also potentially giving farmers the chance to grow alternative crops. Agostini et al. (2020) showed agrivoltaic systems having a positive impact on maize production and water availability. Maize production was higher, and more stable, under agrivoltaic systems than in the open field. Amaducci et al., (2018) demonstrated how reduced radiation under agrivoltaic systems led to more favourable soil and soil moisture conditions for growing maize. Compared to full light conditions, maize grown under agrivoltaics had more stable and higher average grain yield than maize grown in full sun. They also highlighted the potential for agrivoltaic systems to increase crop resilience to climate change by helping to reduce drought stress. Climatic changes year-to-year had more impact on yields than the introduction of photo-voltaic panels and mild shading (defined as a 20 – 35% reduction in radiation) had little impact on grain yields compared to full light conditions. Table A5 brings together the outcomes of a number of studies exploring the impact of agrivoltaic shading on crops and yields.

Table A5: Crop shading and associated yield changes from a number of studies across Europe, adapted from Trommsdorff et al., (2022). Note the differences in yield change at Heggelbach between 2017 and 2018, temperatures recorded across Europe in 2018 were one of the three highest years on record.

Crop	Location	Shading	Yield change
Winter Wheat	Germany, Heggelbach	35%	-19% (2017)
			+3% (2018)
Potato	Germany, Heggelbach	35%	-18% (2017)
			+11% (2018)
Celery	Germany, Heggelbach	35%	-19% (2017)
			+12% (2018)
Clover Grass	Germany, Heggelbach	35%	-5% (2017)
			-8% (2018)
Lettuce (varieties Kiribati and Madelona)	France, Montpellier	Half density, solar tracking, controlled tracking	-5% to -30% Fewer losses on controlled tracking
Lettuce	France, Montpellier	Half density PV panels	-19% to -1%
		Full density	-42% to -21%
Vine Grapes	France, Piolenc	36%	Approx. +25%
		66%	Approx. -25%
Apples	France, Mallemort	Approx. 50%	Similar growth rates with lower water demand. However lower yields due to reduced fruit drop

Chae et al., (2022), reporting on broccoli growing with agrivoltaics in South Korea noted: "*In this study, microclimate, including PPFD and soil temperature, changed under AV, resulting in a small decrease in crop production and altered metabolites in broccoli. The additional shading in AV increased consumer preference for the product by improving its appearance quality*."

Trommsdorff et al., (2023) researched the impact of agrivoltaics in orchards, noting a range of potential positives and negatives. Positives included shade and shelter, potential for reduction in storage rot leading to less apple damage and less need for chemical treatments, shelter reducing the need for hail nets to protect fruit meaning a gain in social acceptance and reduction in hail net (plastic) use. Negatives included rain run-off from panels and subsequent unequal distribution of water and potential for soil compaction during installation, they also noted it could be useful to consider more shade tolerant crop cultivars in association with agrivoltaics. Agrivoltaics can also offer livestock shade and shelter, Handler and Pearce (2022) discuss the efficiencies of having photovoltaics and sheep on pastureland, finding that sheep grazed on pastureland with agrivoltaics meant less productive farmland could be "used twice".

Reduced crop yields or reduced crop growth caused by the shading due to photovoltaic panels could be mitigated by; changing the layout of the panels (such raising them further above the ground), using smaller panels to minimise shading and distribute light more evenly, changing panel orientation so that shade patterns are more homogenous or using semi-transparent panels allowing more light to reach crops (Trommsdorff et al., 2022). Shade tolerant crops could also be considered, Dinesh and Pearce (2016) highlight that lettuce can adapt to shading by increasing leaf area, maximising light uptake, whereas wheat does not and so increased shading can lead to reduced yields.

Agrivoltaics could also be combined with crops for biogas or biofuel production. Amaducci et al., (2018) consider combining agrivoltaics and maize for biogas production. Bao et al., (2023), consider balancing photovoltaics and crops for biogas and how this is influenced by topography or location, where some areas produce more energy from photovoltaics. Cossu et al., (2023) combined photovoltaics and a vertical farming greenhouse system growing baby lettuce. The panels produced electricity used in the lighting and other climate systems of the greenhouses. They noted the need to balance coverage of the greenhouses with photovoltaics in order to generate electricity and maintain light to the crop, finding that high coverage led to increased electricity generation but low yields where income from electricity generation could not make-up for the losses in crop yield.

6.1.14 Economic considerations

In using agrivoltaic systems, farmers need to consider what makes most financial sense for the farm and potential trade-offs between food and energy production. Costs can be incurred through crop shading and loss of land to agrivoltaic systems, some farms may be better placed to "absorb" some of these costs. For example, livestock farms where the set-up of photovoltaic panels enables livestock grazing to continue or farms growing crops where shading has a smaller impact on yields (Fuerbacher et al., 2022)

In respect of the type of photovoltaics used, Trommsdorff et al., (2023) note that more expensive semi-transparent panels could support maintaining yields and yield quality and although they cost more this could be offset by the additional harvest "*Even small benefits in agricultural yield can justify mentionable higher cost on the PV sector. Accordingly, this might allow PV module manufacturers to develop dedicated agrivoltaic PV modules to address a niche market with a higher willingness to pay compared to standard PV modules.*".

Valle et al., (2017) noted that "*Agrivoltaic systems should also be compared in terms of gross margins. Currently, the mean price of one lettuce plant is 0.55 €, resulting in 4.4–7.7 € per square meter, with planting density ranging from 8 to 14 plant per m2. PV production in agrivoltaic systems ranged from 6.5 to 18 kW h m2 with an average 0.13 € purchasing price per kW h, resulting in 0.85–2.34 € per square meter. This simple comparison of purchasing prices, without taking into account any other expenses, shows that the crop yield represents a* *minimum of 65% of the total, economic production of the land, attesting an important role for agricultural production in agrivoltaic systems.*".

Could installing agrivoltaics lead to a loss of subsidies? Are grants or subsidies available for agrivoltaics? "*The results indicate that agrivoltaics in orcharding is only economically feasible if the regulatory framework provides sufficiently high feed-in tariffs or comparable support payments*" (Trommsdorff et al., 2023). Grants, subsidies and payments could be country or region specific and will be discussed in more detail in Deliverable 1.3.

If electricity is being "exported" and used off-farm, is connecting to a national grid (electricity) network easy or even feasible? If energy is going into a national network, where photovoltaics are placed and costs associated with physical changes or additions to the network may be an important consideration. Bao et al., (2023) consider the distance and difficultly in connecting photovoltaic plants to local electricity grids when assessing whether land would be better suited for crops or agrivoltaics and Chatzipanagi et al., (2023) note potential issues in the differing requirements of EU member states in permitting connection of agrivoltaic systems to national grids which can limit connections and increase the time taken to connect to the grid.

6.1.15 Why are some farmers reluctant to grow energy crops or include energy crops in their rotations?

Economic factors

Depending on market price, energy crops may bring less profit than food or fodder crops, and a number of studies have focussed on the economic impacts to farmers of growing perennial energy crops such as Miscanthus and Short Rotation Coppice (SRC) (see, for example, Bocquého and Jacquet (2010); Ericsson et al., (2009); Monti et al., (2009); Styles et al., (2008). The change of land use from growing food or fodder to energy crops, the land available for energy crops, potential yields and the prices offered for crops intended for consumption or energy production are important factors in farmers decision making.

Paulrud and Latilla (2010) explored, through choice experiments, the attitudes of Swedish farmers towards energy crops. They found subsidies, visual impact and the rotation period of the crop had significant impacts on whether farmers were inclined to grow energy crops or not. "*The survey results showed that there is an increased interest among farmers to start growing willow, reed canary grass, hemp, and energy grain provided that the net income is high enough*."

Fraji and Jayett (2018) discuss the growing of Miscanthus as an energy crop and found this was dependent on its yield potential and profit margins. Miscanthus could compete with profitable food crops on marginal land in northern and southern France, if Miscanthus nitrogen requirements were low, prices offered for Miscanthus biomass were high and farmers could choose to delay the rotation period. Increasing prices for oil will also play a role in the potential profitability of biofuels.

Bocquého and Jacquet (2010) highlight that farmers need to be offered attractive contracts to grow energy crops (switchgrass and miscanthus in this instance) in order to develop a secure, long running supply for processing plants. Wilson et al., (2014) cite lack of market, particularly a local market in some cases, for the crop as a reason a number of farmers gave for not growing energy crops. A lack of local market for energy crops may not only mean difficulties for some farmers in selling energy crops but also an increase in the distance biomass needs to be transported for processing, increasing the cost of transportation and associated greenhouse gas emissions.

Knapek et al., (2021) discuss issues around profitability of energy crops and the "competition" between growing food / fodder and energy crops, farmers are unlikely to be willing to grow energy crops unless they are able to gain at least the same economically as they would from conventional crops. They suggest economic support for farmers in the early stages of growing perennial energy crops [Miscanthus] as biomass production following establishment can initially be low.

Erison et al., (2009), considering costs of food crops vs the costs of energy crops, both annual and perennial: "*The cost of land was calculated as the opportunity cost based on the production of cereals. Thus, higher food prices lead to higher land costs, which in turn lead to higher energy crop production costs.*"

Annual vs. perennial energy crops

Perennial energy crops may require several years before they produce enough biomass to harvest or have an economic benefit, whereas annual energy crops can be included as part of rotations with food / fodder crops.

Jonnson et al., (2011) suggested that the growing of annual energy crops kept options open to move back to growing food / fodder crops if energy crops were unsuitable economically or for the land available. Farmers can view perennial crops, such as SRC willow as financially risky (Warren et al., (2016), and committing land for a long period of time (Wilson et al., 2014).

"Not what a farmer does", farmers produce food, not energy

Social, societal and community expectations of "what farmers do" may have an impact on their interest in, and willingness to grow, crops specifically intended for energy production. Focus groups with Swedish farmers undertaken by Jonsson et al., (2011) highlighted how some farmers felt that growing energy crops could be seen as abandoning traditions and undoing the work of past farmers who had maintained and improved the land for growing food. Some viewed the growing of energy crops as unethical, likening it to "burning food".

Warren et al., (2016) while looking at Scottish farmers attitudes towards growing SRC noted non-financial factors including identity, farming culture and the perceived priority to be growing food were very important factors in farmers negative views of growing SRC.

Helliwell (2018) researching the adoption of energy crops (Miscanthus and SRC willow) in the UK, and the potential of marginal land for growing energy crops, highlighted farmers did not perceive their land to be "marginal enough" for growing energy crops. "Energy crops being suitable for poorer land, rather than being a source of attraction mean farmers consider the crops to be second rate".

Land not appropriate for energy crops

The topography may be unsuitable for crops or the machinery required for harvesting, land may also be part of environmental schemes, for example Wilson et al., (2014) highlight "no ploughing" as land is an ESA (environmentally sensitive area) or is part of a UK National Park. They also note farmer responses regarding the land – not enough to grow energy crops in addition to what is already grown, unsuitable topography for equipment access, soil too poor, weather and soil too wet.

Gaffey et al., (2023) note how changes to what is grown – the example they give is changing from a permanent grassland to a temporary one for the purposes of growing grasses for biorefining – can change the potential for carbon capture in the grassland and biodiversity – this could have impacts (for example) on the subsidies received.

What are their peers doing? What do their advisors recommend? Where are the knowledge gaps?

Kolady et al., (2021) noted that peers were important in introducing aspects such as diverse crop rotations. Ditzler et al., (2021) discuss the mis-alignment between the information available in the peer-reviewed literature and what farmers want to know about rotations. They highlight the need for a broader spread of research into crop rotations and diversification to support farmers and advisors. Wilson et al., (2014) highlight that: "*It is informative to note that while 'no local working example' was cited by over 10% of farmers as a reason for not being willing to consider growing either of these crops [miscanthus and SRC Willow], the presence of a 'local* *working example' has also been cited by a small number of respondents as a reason for not being willing to consider growing either crop.*"

Wilson et al., (2014) make a number of recommendations to support the uptake of growing energy crops by livestock farmers including:

- Maintenance grants and on-going area-based payments for energy crops could address the issues around the gap between planting and gaining a financial return
- Government-backed output contracts providing a guaranteed market for the crop
- Incentivising energy crop production via eligibility for energy subsidy payments (e.g. Renewable Obligations Certificates [ROC]) could improve their profitability
- Targeting both farmers and landlords with respect to policy messages to overcome tenancy restriction faced by some farmers.
- Geographic targeting of support within a specific radius of a biomass plant location, or co-supporting biomass plants alongside farm-level biomass production may also be required.

6.1.16 SWOT analysis and concluding points

Table A6 summaries the Strengths, Weaknesses, Opportunities and Threats from the literature of on-farm anaerobic digestion (biogas production) and agrivoltaics.

Table A6: SWOT analysis of biogas production and agrivolatics from the literature

Strengths	Using waste products / bi-products Potential to use marginal or unproductive land Additional farm business income Reducing fossil fuel use Shading and reduced crop irrigation Bi-products of anaerobic digestion, e.g. fertiliser Producing own energy – self sufficiency Solid waste disposal
Weaknesses	Societal and farmer negative views of biogas plants and agrivoltaics Lack of funding / grants for development Loss of crops and land for growing food / feed crops Cost of construction (solar panels, biogas plant) Time gap between installing and potential profitability Maintenance costs Some bi-products not “waste”, e.g. straw – livestock bedding
Opportunities	Increasing power (electricity, fuel, gas) costs Net zero and greenhouse gas reduction policies Increasing demand for green energy Decreasing costs and increasing efficiency of photovoltaic systems and biogas plants Conservation and biodiversity Rural and regional development / potentially employment Combine farm and domestic waste – landfill and waste reduction
Threats	Food, feed and energy crop price changes Changing climatic conditions Changing costs of installation Changing rules on use of crops / land Future CAP changes Changing planning regulations Changing political priorities

A holistic view needs to be taken of combining food and energy production on farms. Agrivoltaics enable on-farm electricity generation, however the set-up of photovoltaic panels and the crops grown alongside them needs to be considered to minimise yield reductions from shading or selecting crops that would benefit from shading.

Biogas generation from dedicated energy crops can enable energy generation on and off-farm, but may offer farmers a way of making use of agricultural waste and bi-products and generating additional farm income. This use of waste and byproducts to generate biogas and energy, rather than dedicated energy crops, may be a growing area.

Economic factors play a substantial role in farmers decision making around combining food and energy production. Perennial energy crops may have a long lead in time before harvest, agrivoltaic systems and anaerobic digesters can be expensive to install and maintain and again, there may be a long lead-in time before farmers see any economic gain.

Any move towards installing agrivoltaics or biogas production needs to take into account the energy use and production across a wide range of variables. For example, having larger centralised municipal digesters means more waste can be utilised, but increases energy use in transporting to the digestor. Some crops require higher inputs of fertilisers, but in turn have higher methane yields when used in biogas generation

Adapting crop rotations can provide a way of maintaining food / feed production while growing some dedicated energy crops, utilising crop wastes and supporting soil health.

Changing energy and food prices are an important consideration, impacting on farm income and profitability. For example, increasing oil prices could make biofuels from dedicated energy crops more attractive than food crops.

There are a wide range of environmental considerations in supporting energy production. For example, focussing on crops that require less input, how using agrivoltaics can reduce the need for e.g. irrigation, , looking at how having e.g. smaller local biogas plants can reduce transportation. There also needs to be consideration of the environment in terms of region, for example different crops or types of agrivoltaics depending on farm "type" and area, different crops and rotations in northern and southern Europe. The impact of agrivoltaics may be increased on particular crops in more northern regions.

Pulling together all the information to work out all the "variables" such as changes in crop production, the amount of energy produced by biogas or agivoltaics, the types of crops to grow or crop waste that can be used, rotations to both support the soil and environment, reduce fertilisers and grow crops for energy production is time consuming, farmers and advisors need access to information and support in order to effectively implement changes.

The review suggests that access to regional demonstration sites will help expose farmers to the possibilities of integrating food and energy production as will the effective use of "champion" farmers who are in the successful vanguard of adopters. Such demonstration sites can also illustrate the types of cropping protocols that will enable successful integration of food and energy production, as well as illustrating the "physical" infrastructure required for successful adoption. It is clear that training related to the on-farm possibilities will encourage adoption, as will more information on the financial aspects of integrating food and energy production. A potential framework for such training is provided later in this document.

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6.2 DECISION SUPPORT TOOLS LITERATURE REVIEW

6.2.1 What are Decision Support Tools?

Decision Support Tools (DSTs), sometimes also referred to as Decision Support Systems (DSSs), can be used by farmers to help them make more effective decisions by "leading them through clear decision stages and presenting the likelihood of various outcomes resulting from different options" (Rose et al., 2016). Tools may be online, software or paper-based and can support farm and land management through enabling accurate and effective recording of data, analysis of this data and subsequently offering evidence-based recommendations (Rossi et al., 2014; Adereti et al., 2023).

With increasing quantities of agricultural data available to farmers, from data collected on farm relating to yields and fertiliser use, to Earth Observation (EO) data on crop growth collected by satellites, the potential for DSTs in handling and processing these data and making recommendations or suggesting options to support farmers in their decision making, is substantial.

DSTs can be structured in a variety of ways. They could be apps or software that enable recording or collation of data, for example yields, pesticide and fertiliser applications alongside maps and precise locations (GPS) for precision farming, leading to making evidence-based decisions relating to farming inputs. A flowchart or decision tree style could lead farmers through a series of decisions on multiple and related aspects of farming, for example linking carbon and greenhouse gas emissions, on-farm fuel use and carbon capture. Online courses or OOCs (Open Online Courses) can provide opportunities to learn about new and developing technologies in farming and explore how they can be applied on individual farms. DSTs could also be modelling systems used in research, these are not necessarily available directly to farmers, but may be used in a research framework to support a farmer in decision making, for example Amaducci et al., (2018), who use a modelling system to explore how best to site agrivoltaics to maximise both electricity generation and crop production.

DSTs can also have an educational type role, Debeljak et al., 2019, describe how the DSS Soil Navigator, which explores various soil functions such as nutrient cycling and carbon sequestration, can also function as an educational tool, providing "... *an opportunity to gain knowledge about different soil functions and how they are affected by management strategies under certain soil and environmental conditions*" and that using DSTs can enable and encourage discussion between farmers and farm advisors.

6.2.2 Are DSTs used by farmers?

Overall, uptake and use of DSTs by farmers appears to be low (Rose et al., 2016; Rose et al 2018). However, increasing use of agricultural technologies, such as precision farming and the use of EO data in monitoring crop growth, could change this. A number of studies (for example Morinko et al., (2023) and Bechtet et al., (2023)) have found that while uptake and continued use of DSTs by farmers may be low, DSTs are being used to support decision making in farming. Iakovidis et al., (2023), surveying a region of Greece, found 70% of agronomists (advisers) used DSTs in relation to agribusiness planning and management and of these 80% viewed them positively. They noted that, in general, farmers had become more open to using DSTs over recent years, but lack of technological know-how in using systems or interpreting results from them and lack of transparency and ease of use in the tools reduced their likelihood of being used.

6.2.3 Why are DSTs used / not used?

A number of studies have explored why farmers do or do not use DSTs to support management of their farms. Here these reasons have been broadly divided into six categories: 1) Social and legal reasons; 2) Issues around the use and application of technology; 3) How co-production or co-design can support uptake; 4) Knowledge of both the end-user and the knowledge used to develop the DST; 5) The transferability of the DST and its contents; and 6) Dissemination of the DST.

Social and legal:

- Data ownership can be a concern, if farm level data is inputted, who does the data belong to? The ownership of any outcomes and results of analysis also need to be considered. Related to this, if a DST is part of monitoring system, for example in relation to compliance or allocation of subsidies, it could be seen as intrusive.
- Cost may be relevant. Urquhart et al., (2023), note that while no cost / free may be useful, there is a perception that paid for DSTs could provide a better service (you get what you pay for…). Likewise, some may be unwilling to pay for DSTs they are unsure they will use them or do not fully trust them (Marinko et al., 2023).
- Rossi et al, (2014) highlight how involving end users in the development of a DST "... *provided information on end-user willingness to pay for and use the DSS*".
- Cost of data to support DSTs can be an issue, for example the cost of collection, cost of analysis and cost of dissemination (FAO, 2003).
- Time available – do farmers have the time to use and learn how to use and implement to ideas coming from DSTs? DSTs have the potential to save time in handling and processing large quantities of agricultural data (Zhai et al., 2020) but can require an initial input of time in order to make use of this.
- End-users interest, ability and openness to using new technology (Iakovidis et al 2023). Will the DST support their decision making (Marinko et al., 2023)? Do they have the skills and knowledge they need to effectively use the DST and interpret the outputs (Bechet, 2023)?
- Various factors, such as farmer age, level of education and openness to using new technology influence uptake levels (Bechtet, 2023; Iakovidis et al., 2023; Marinko et al., 2023).

Technology:

- The technology may not be usable or accessible, for example, it relies on internet connection which may be patchy "in the field" (Marinko et al., 2023). Has it been designed to be user-friendly? Will farmers need training in how to use it (Adereti et al., 2023)? Or do they have the perception they will need training in how to use the DST and this is off-putting (Marinko et al., 2023).
- Can the DST be, and is it, updated? (Nicholson et al., 2020) If regulations change (such as compliance rules), the science changes (new research is available) or the "products" (e.g. pesticides, fertilisers) available change, is this reflected in the DST (Oliver et al., 2012)?
- Are the DST's an integrated part of a system already used by the farmer, for example the software associated with John Deere hardware for precision farming also offers DST elements? Also related to this is interoperability, can the DST take data acquired from a different app or piece of software and use it? (Zhai et al., 2020)
- Flexibility – "ALIS's layered structure makes ALIS flexible enough to incorporate context-specificity, changes in data availability and changes in policy vision, while still preserving stability in the foundations of the tool" (Kerselaers et al., 2015).
- If earth observation (EO) data is required, is it accessible and available to farmers and at a relevant scale, for example field, farm or region (FAO, 2003).
- There needs to be consideration around user interfaces and how data and recommendations are presented (Zhai et al., 2020). Are they accessible to the end-users?
- DSTs may need to take into account historical data, or predictive or modelled data, is this available to the farmer and in a format suitable for the DST? (Zhai et al., 2020)

Co-design and co-production

- DSTs may not be designed for the farmer (end-user) and don't take into account farmer's needs, technological availability or know-how.
- Ownership of the tool – being involved in development of the tool, which can support understanding of how it works and brings data together and knowing where the data used in the tool comes from. Transparency can make end-users more confident in using the tool (Kerselaers et al., 2015).
- A number of studies emphasise the importance of involving farmers in the design and development of DSTs in order to support their use and uptake, e.g. Adereti et al., (2023), Oliver et al, (2012); Arulnathan et al., (2020), Rossi et al., (2014).
- Arulnathan et al., (2020) recommend: "*Making the development transparent, sharing not just the data sources and modelling used within the tool but also sharing the process of development*".

Knowledge

- Is suitable support for the DST (for example instruction manuals or in-person support) available to farmers? (Nicholson et al., 2020).
- There may be language constraints. Are DSTs available in farmer's own language? In accessible and non-technical language? (Urquhart et al., 2023; Nicholson et al., 2020)
- Consistency between DSTs is important to enable trust from end-users. Do different DSTs deliver the same response or advice? (Nicholson et al., 2020)
- Does the DST use expert and / or up-to-date knowledge? (Zhai et al., 2020; Aderati et al., 2023)
- Have developers considered combining tools and already existing DSTs to meet user needs? (Okpara et al., 2020)
- "*Ensuring decision support methods (e.g. benchmarking, monitoring progress and scenario comparison) are used to support the decision-making process*" (Arulnathan et al., 2020)

Transferability

- Nicholson et al., (2020) highlight the value of regionally specific DSTs, or DSTs that can support regionally specific aspects, for example, planning regulations or funding relating to agrivoltaics may be different between countries. They highlight: "*Key obstacles to exchange include differences in legislation, advisory frameworks, country-specific data and calibration requirements, geo-climate and issues around language.*"
- Arulnathan et al., (2020) reviewed 19 DSTs associated with the Agri-Food sector and found "DSTs that focus on a specific agri-food sector, have narrower geographic scope and consider multiple dimensions of sustainability appear to be most efficacious."
- Language, depending on who or where the DST is aimed at, is it (for example) in the farmers native language? Or is it aimed at (for example) advisors known to be proficient in this language who can then work through the DST with the farmer?

Dissemination

- Dissemination of DSTs, how do farmers find out about DSTs? And what would encourage an end-user to recommend a DST?
- Recommendations from "non-marketing" sources may be more likely to be trusted, for example Agricultural Advisors can be seen as trusted sources for DSTs (Marinko et al., 2023) and (Bechtet, 2023) highlight that Advisors have an important role in encouraging and enabling uptake and use of DSTs by farmers.
- "*We have identified the need to organise educational or demonstration workshops as well as including DSS training in agricultural schools and universities as one of the most promising pathways to increase the uptake of IPM DSS in Europe, which should aim at informing farmers and farm advisors about the features and benefits of IPM [Integrated Pest Management] DSS.*" (Marinko et al., 2023)

- Iakovidis et al., (2023) also highlighted their findings that evidence-based DSTs were more acceptable to farmers, and that state-based promotion of DSTs and subsidisation of the establishment costs and training would be the most effective way to encourage DST uptake.

6.2.4 Suggestions for coproduction

A number of studies emphasise the importance of involving farmers in the design and development of DSTs in order to support their use and uptake, e.g. Adereti et al., (2023), Oliver et al, (2012); Arulnathan et al. (2020), Rossi et al., (2014). Urquhart et al. (2023) provide 11 recommendations for improving farmer engagement with DST's (Figure A8).

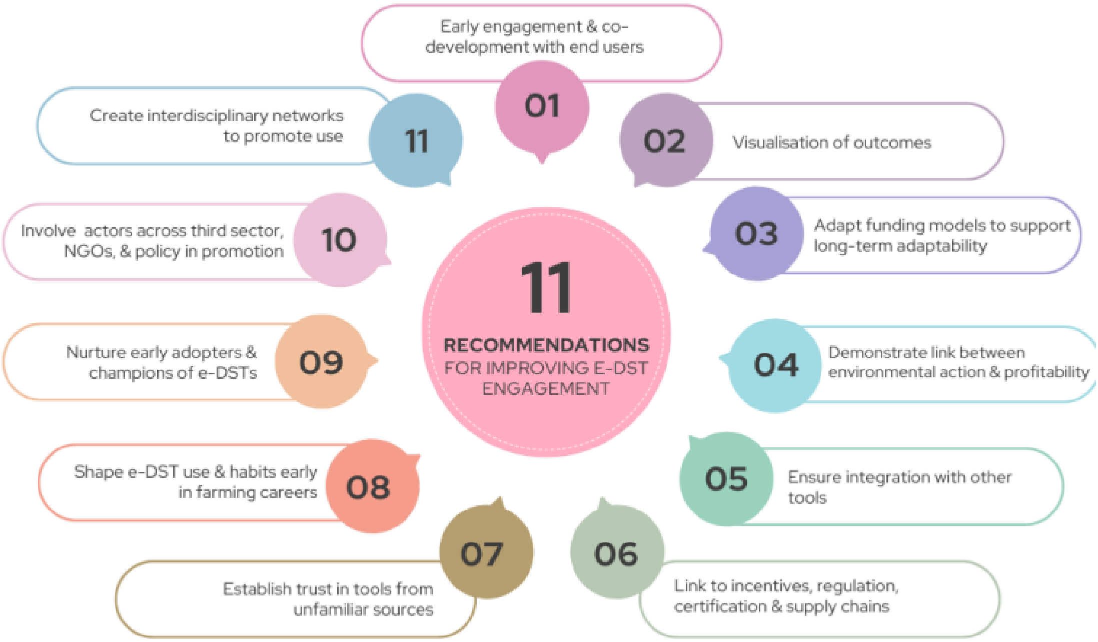


Figure A8: Recommendations for improving e-DST engagement (taken from Urquhart et al., 2023)

Nicholson et al., (2020) highlight the criteria that end-users consider that DSTs need to fulfil (Figure A9).

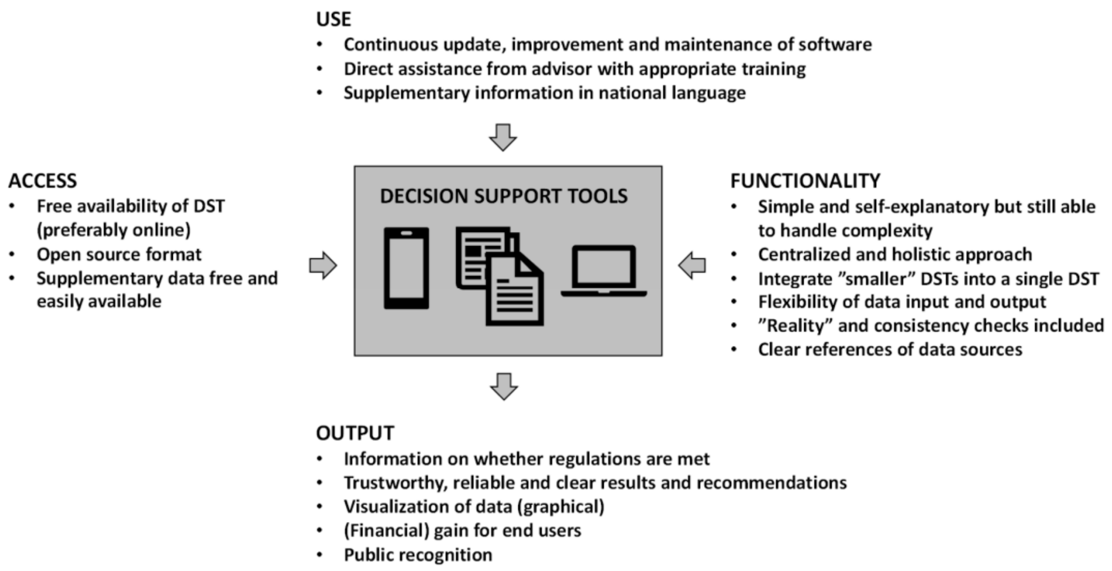


Figure A9: End-user criteria for DSTs (Nicholson et al., 2020)

6.2.5 Current examples of DSTs

Due to the nature and time constraints of this review, this does not represent a systematic review of DSTs available to the agricultural sector. The aim was to explore the type of DSTs available and then to focus on those relating to food and energy production or use that were aimed at farmers and /or advisors. As such this is not a complete list of DSTs available, and new DSTs may have been made available or removed.

As DSTs can be presented in a range of formats the definition of Nicholson et al., (2020) in identifying DSTs was used to support identification of DSTs: "*For the purposes of this review, a DST was defined as any bespoke (i.e., custom-made) or generic (i.e., 'off the shelf') software, email/text alerts, online calculator or guidance, phone app, and paper-based guidance that could contribute to an end user decision [affecting surface or ground water quality.]*"

Also of note: The search for DSTs was undertaken in the English language. Google and Google Scholar will only search for the specific search terms used (I.e. in that language only, searching for "Decision support tool" in English will not find websites which include this term in another language) this will not have pulled out DSTs in other languages, which may be more specific / relevant to particular countries. A wide range of DSTs will be discussed in peer-reviewed publications and therefore can be found through searches of databases such as Web of Science, in these instances the publications are in English and the DST may be available in other languages. Searches for DSTs were also made using Google in Greek, Italian and Dutch to confirm if searches in alternative languages highlighted any additional DSTs.

A range of websites, databases and publications were searched for examples of DSTs:

- Web of Science, Google and Google Scholar were searched using a range of terms: DST, DSS, farming, agriculture, Decision Support Tool, Decision Support System
- Agricultural / Farming Organisations e.g. Food and Agriculture Organisation (FAO - https://www.fao.org/home/en) and National Farmers Union (NFU - https://www.nfuonline.com/)
- Search of Cordis (CORDIS | European Commission (europa.eu)) for EU funded projects

- Lists of DSTs in peer reviewed publications, review articles and published project reports, including: Rose et al. (2016), Gutiérrez et al., (2019), Arulnathan et al. (2020), and Fairways project (https://fairway-is.eu/index.php/documents/category/10-decision-support-tools)
- Aggregation websites, e.g.: https://agledx.ccafs.cgiar.org/resources/tools-calculators/ ; https://data.nal.usda.gov/search?query=lca%20tool
- OOCs and online courses from a number of organisations and providers, e.g. FAO, FutureLearn, Coursera, udemy, edX
- Search of App stores, including GoogleApp store and Apple App store

In this review DSTs that: i) focussed solely on livestock and livestock management; ii) focussed solely on the financial / economic aspects of farming (many DSTs include this as part of decision making but it is not the sole focus); iii) DSTs focusing on crops not grown within Europe (e.g. sugarcane and oil palms); and iv) DSTs focussing solely on aspects of farming such as pesticide / herbicide / fertiliser application, water quality, soil management, pest control with no consideration around food production or energy use and/or production were excluded.

6.2.6 Reviewing existing tools (integrated energy and food production)

Section 6.2.9 provides a summary table of DST's which are potentially relevant, they may include elements of food production, energy use or both. For each DST the following data are recorded:

- Name
- Short summary / description on the DST, often taken from the DST or associated website
- Language(s) the DST is available in
- Cost – this may be a one-off cost, subscription or it may be free
- Type – is it (for example) an audit, course, transition tool, data collation tool...
- Geographical region – is the DST only relevant / usable in a particular area or region?
- Themes / Focus – e.g. crop management, carbon capture, energy use
- URL / link

6.2.7 Summary of existing tools

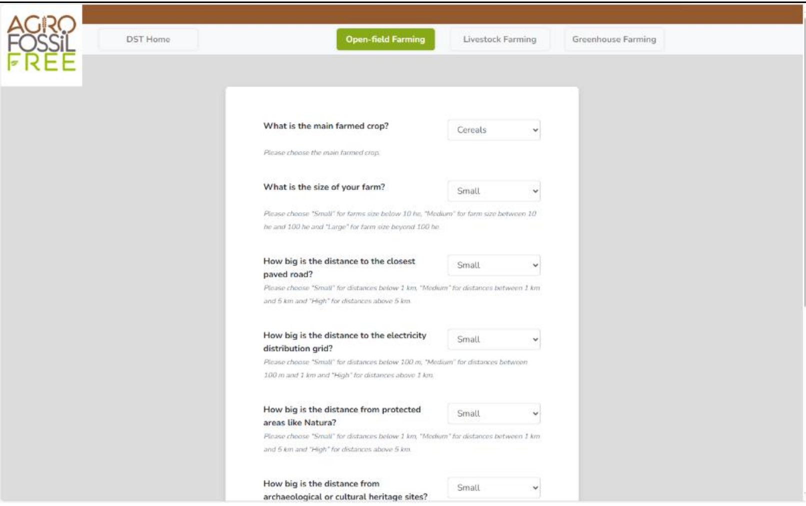
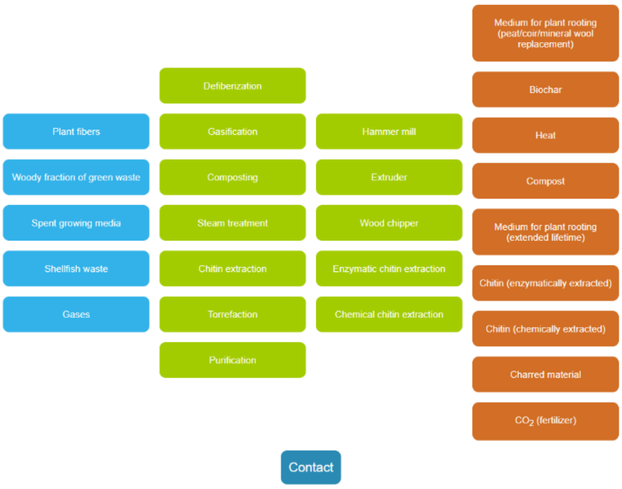
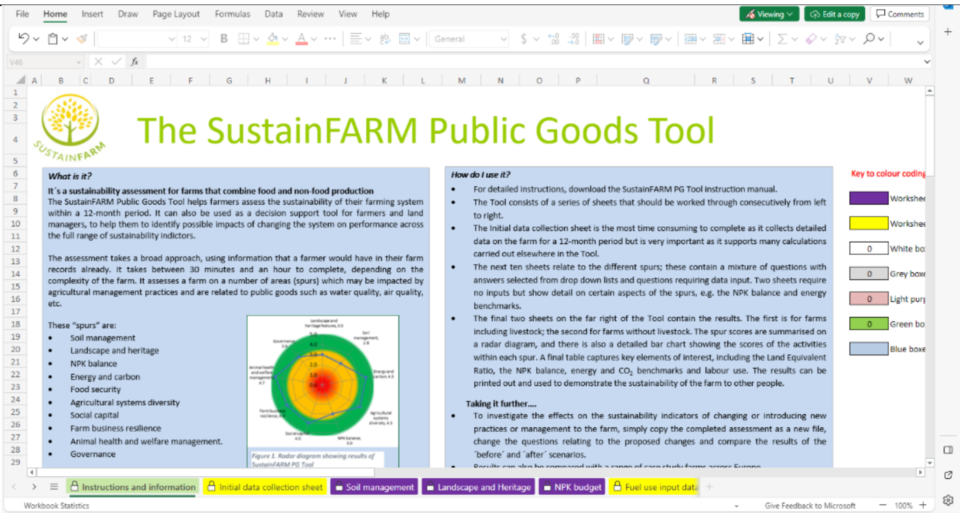
Overall, there appears to be an extensive range of DSTs available on a wide range of aspects of farm and agricultural management. Some are aimed at farmers, advisors / agronomists, and some at those associated with farm businesses (e.g. accountants), policy maker and ecologists / environmentalists associated with farming.

In general, there appear to be few DSTs which consider both energy and food production in agricultural settings. The majority focus on food production (crop management), considering how to improve yields and reduce or apply inputs (e.g. fertilisers or pesticides) more effectively. An increasing number of DSTs consider carbon and greenhouse gas emissions, and as part of this may consider how to reduce energy use or introduce renewable energy generation on farms. There were also a number of DSTs (not recorded as part of this review) focussing on aspects of farming and land management such as water quality, soil health and pollution reduction.

In terms of design or set-up, many DSTs and DSSs offer opportunity to bring together various farm level data in an app which can then support decision making by farmers. Some offer a "flow chart" style decision support, some an audit, a course, a knowledge space (which can be personalised bringing together specific news, reports and research), data aggregation and collation to aid decision making, some offer case studies, compliance advice and guidance and links to information about subsidies or agricultural products.

Screenshots of some example DSTs are shown in Table A7.

Table A7: Example DSTs

<table>
<tr>
<td>
</td>
<td>AFF-Decision-Support-Toolkit (agrofossilfree.eu) - Audit style, enter data and recommendations given</td>
</tr>
<tr>
<td>
</td>
<td>Decision Tool - Horti-BlueC flowchart style, answer questions and follow the decision process for recommendations. On-line flowchart</td>
</tr>
<tr>
<td>
</td>
<td>Decision Support Tool - SustainFARM Audit and potentially transition type - enter data relating to various aspects of the farm, recommendation to improve on-farm sustainability. Excel spreadsheet</td>
</tr>
</table>

The majority of DSTs found were available in English (although the search process may have been biased towards finding DSTs in English). Some were also available in alternative or multiple alternative languages. In some cases (depending on the format of the DST) Google translate may be able to support use of the DST if it is not available in a user's native language.

Regionality may also be important aspect to consider. While many of the DSTs found appeared to be widely geographically applicable, for example through using EO or GIS data to support mapping and recording data, or relying on farmer inputted data, some were specific to a country or region. In these cases the DST may have been supporting decision making on specific aspects of farm management, such as compliance regulations which were specific to a country or relating to the climate or crops grown in a particular region (for example olive growing in Mediterranean regions).

The DSTs found during this review were developed and produced by a variety of organisations, research projects and companies, some not-for-profit, some businesses. Some were freely available and some charged for. Some may have a free, more basic, DST and charge for similar DSTs with an increased number of functions, some were subscription-based or required membership of the developing organisation.

The maintenance and sustainability of DSTs may also be an issue. Some DSTs reported in peer-reviewed literature (e.g. found through Web of Science searches) or evaluated as part of review papers are now unavailable. The hosting website may no longer be live or maintained. Some relevant to this review were:

- CO2MPUTOLIV 1.0 – energy use and GHG emissions in olive growing (Gkisakis et al., 2020)
- BioenNW - a method and a model are being developed for the assessment of sustainable potentials and the corresponding spatial distribution of all relevant organic residues (agricultural residues, forest biomass, urban waste) in specific European regions." https://www.itas.kit.edu/english/projects_knap12_bioennw.php
- AgroDSS - A decision support system for agriculture and farming (Rupnik et al., 2019)

It is also worth noting that some research papers describe the development of a prototype DST which may not lead to a fully developed, widely available DST.

6.2.8 References

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6.2.9 Table of existing DSTs

Table A8: Table of existing Decision Support Tools

Name	Language	Cost	Type	Geographical region	Themes / Focus	URL
365Crop	English	No cost	Data collation	None specified	Crop management	https://play.google.com/store/apps/details?id=com.farmnet365.pflanzenbau&hl=en&gl=US
AgAssist	English	No cost	Information	None specified	Crop management	AgAssist - Apps on Google Play
Agrecalc	English	Free to farmers	Audit	UK	Carbon / GHG emissions	https://www.agrecalc.com/
Agricolus	English, Italian, Spanish	Varying levels, some free	Audit, Data collation	None specified	Crop planning and management	https://www.agricolus.com/en/solutions/
AgriculTural LandscApe Simulator (ATLAS)	English	No cost	Modelling	None specified	Crop production	https://www.comses.net/codebases/5416/releases/1.2.0/
Agriculture, Economics and Nature	English	Free to access	Course	None specified	Farm management	https://www.futurelearn.com/courses/agriculture-economic-nature
AgriNet	English	Annual fee (€130)	Audit / Data collation	Ireland	Grassland management	https://www.agrinet.ie/
Agrivi	Various including: English, French, German, Italian, Polish, Romanian, Spanish	Cost unknown	Audit / Data collation	?Global	Crop management, Farm management	https://www.agrivi.com/

AgroFossilFree	English	No cost	Audit / Transition?	?	Energy use / Energy technologies	https://dst.agrofossilfree.eu/
AgroPlanning	Spanish, English, French, Dutch	Monthly subscription	Data collation / Monitoring	?None specified	Crop monitoring, Farm machinery monitoring	https://www.agroplanning.com/en
AQUACROP	? English, Spanish	No cost	Audit	Global	Crop management	https://www.fao.org/aquacrop/en/
Arla Forage Budgeting App						https://www.alltech-e-co2.com/e-co2-delighted-announce-release-forage-budgeting-app-supported-arla-foods/
Bayer FieldMate	?English	No cost	Information / Identification	None specified	Crop management	https://cropscience.bayer.co.uk/tools-and-services/agronomy-tool-app/ https://play.google.com/store/apps/details?id=com.bayer.agronomytool&gl=GB
BioEnergy Farm	Italian, English (?)	No cost?	Audit	?	Energy use and production	http://www.bioresource4energy.eu/
Carbon Support Tool	English	Free pilot	Audit	UK	Carbon capture	https://www.i4agri.org/climate-smart-farming
COMET-farm	English	?No cost	Audit / Transition?	?USA	Carbon, GHG, energy use	https://comet-farm.com/
Cool Farm Tool	Multiple	Free to farmers and growers	Audit	Global? Some limits e.g. biodiversity currently covers Temperate Forest biome and the Mediterranean and Semi-Arid biomes.	greenhouse gases, biodiversity, water use and food loss & waste	https://coolfarm.org/the-tool/

Crop Rotation on Organic Farms (SARE)	English	Online copy available for free	Audit / Transition?	None specified	Crop management, Crop rotation	https://www.sare.org/publications/crop-rotation-on-organic-farms/a-crop-rotation-planning-procedure/a-complete-step-by-step-rotation-planning-guide/
Croprotect	English	No cost	Knowledge exchange	UK	Crop pest management	https://croprotect.com/
CropSAT	English	No cost	Data collation / Monitoring	None specified	Crop monitoring, Farm machinery monitoring	https://cropsat.com/
Decision Support System for Agrotechnology Transfer (DSSAT)	English	No cost	Modelling	?None specified	Crop production	https://dssat.net/
Discover Best Practice Farming for a Sustainable 2050	English (and additional languages as subtitles)	?No cost	Course		Sustainable farming	https://www.coursera.org/learn/best-practice-farming-sustainable-2050
Dual Purpose Cowpeas and Millet with and without Farmer-Managed Natural Regeneration in Senegal	English	No cost	Audit	Senegal	Carbon emissions	https://senegaldst-dev.ags.io/
Dyrkningsvejledninger (Cultivation guidelines for crops in agriculture)	Danish	Free	? Personalised updates / information	Denmark		https://www.landbrugsinfo.dk/basis/b/d/9/dyrkningsvejledninger

ECO2VINE	?	?		?		Early access paper: DOI10.1007/s10668-023-03649-4
Electric Farming	English	Approx £20	Course	None specified, variety of global examples used	Enegy use and generation	https://www.udemy.com/course/electric-farming/
Farm Carbon Calculator	English	Free to farmers and growers	Audit	UK	Carbon emmsions, Energy use	https://calculator.farmcarbontoolkit.org.uk/
Farm Sustainability Assessment	English	No cost	Various - incl course, audits - Hub	Global	Sustainability	https://saiplatform.org/fsa/
Farm Sustainability Readiness Tool	English	?No cost	Audit / Transition?	?Canada	Sustainability, including energy use	https://www.farmsustainability.ca/en
farmable	English	Free to download, in app purchases				https://play.google.com/store/apps/details?id=tech.farmable.farmable&hl=en_GB&gl=US
Farmers Guide to Energy Audits	English	No cost	Audit	UK	Energy use	http://www.calu.bangor.ac.uk/energybooklet.php.en
FARMPLAN	English	?No cost	Audit / Data collation	UK	Crop management, Compliance and others	https://farmplan.co.uk/
Farmscoper	English	No cost	Audit	England and Wales	Farm pollutants	https://adas.co.uk/services/farmscoper/
FaST	English, ?Spanish	?No cost	Data collation / Monitoring	Europe	Sustainability	https://fastplatform.eu/
Field to Market	English	No cost	Audit	?None specified - USA focus	Sustainability	https://calculator.fieldtomarket.org/

fieldmargin	English	Free to download, in app purchases				https://play.google.com/store/apps/details?id=com.fieldmargin&hl=en_GB&gl=US
Greenhouse Gas Calculator for Cropland	English	No cost	Audit	None specified	Greenhouse gasses	https://ghgmitigation.irri.org/knowledge-products/mrv-toolbox/sector
HOLOS	English, French	No cost	Audit / Modelling	Canada	GHG emissions, Soil Carbon	https://agriculture.canada.ca/en/agricultural-production/holos
Horti-BlueC decision tool	English	No cost	Audit / Flowchart	? None specified	Biomass waste utilisation	https://www.horti-bluec.eu/en/decision-tool
Information System for Integrated Plant Production (ISIP)	German	?	Audit / Data collation?	Germany	Crop production	www.isip.de
Innovation in Arable Farming: Technologies for Sustainable Farming Systems	English	Free to access	Course	None specified	Crop management, Energy management and others	https://www.futurelearn.com/courses/innovation-in-arable-farming
Integrated Farm System Model	English	No cost	Audit, Modelling	?None specified	Food production, yields, nutrients	https://www.ars.usda.gov/northeast-area/up-pa/pswmru/docs/integrated-farm-system-model/
Leaf Sustainable Farming Review	?English	Membership required	Audit	None specified?	Crop management, Energy management and Others	https://leaf.eco/farming/review
MagicScout	English	No cost	Data collation, Information	None specified?	Crop management	https://play.google.com/store/apps/details?id=com.bayer.cs.magicscout&gl=GB

My Crop Manager (App)	English	Free to download, in app purchaes		Non specified		https://play.google.com/store/apps/details?id=com.bivatec.crop_manager&hl=en_GB&gl=US
MyEasyFarm	French	Annual subscription	Data collation	?France	Crop planning and management	https://www.myeasyfarm.com/solutions/myeasyfarm/
NDICEA - Nitrogen Planer	English, Dutch, Spanish	No cost	Audit	None specified	Crop management, Nutrient management	https://organic-farmknowledge.org/tool/31675
NMP (Nutrient Management Plan) Online	English	Cost depends on level of use		Ireland	Crop management	https://www.teagasc.ie/about/our-organisation/connected/online-tools/teagasc-nmp-online/
Nordzucker Agri Portal	German, Danish, Finnish, Lituanian, Polish, Slovakian, Swedish	Some no cost, some membership only	Information, data collation	Germany, Denmark, Finland, Lithuania, Poland, Slovakia, Sweden	Crop management	https://www.nordzucker.com/en/agriportal-2/
Ofoot	English	No cost	Audit	None specified	Carbon emissions	https://ofoot.cafltar.org/
Omnia	English	Varying levels, some free	Audit / Data collation	?UK	Crop management, carbon management and others	https://omniadigital.co.uk/
PLANET (Planning Land Applications of Nutrients for Efficiency and the environmenT)	English	No cost	Audit / Data collation?	England, Wales, Scotland	Crop and nutrient management	https://www.planet4farmers.co.uk/Content.aspx?name=PLANET
Rhiza	English	Variable costs, some free	Data collation	?UK	Crop management	https://www.rhizadigital.co.uk/

RISE – Sustainability analyses for agricultural holdings	English, ?German	Variable fee	Audit / Transition / Consultancy	Global	Sustainability	https://www.bfh.ch/en/research/all-our-consulting-services/rise/
Sencrop	English	Variable costs	Information	Europe	Crop management, Weather	https://sencrop.com/uk/
Skifteplan	Norwegian	Variable costs	Data collation	Norway	Crop management	https://www.skifteplan.no/
Soil Navigator	English	No cost	Audit	None specified	Soil management	www.soilnavigator.eu
SPIES (Solar Park Impacts on Ecosystem Services)	English	No cost	Audit?	UK	Energy generation, Ecosystem serives	https://www.lancaster.ac.uk/spies/
Sustainability Assessment of Food and Agriculture systems (SAFA)	English	No cost	Audit	?Global	Sustainability	https://www.fao.org/nr/sustainability/sustainability-assessments-safa/en/
SustainFARM Public Goods Tool	English	No cost	Audit, Transition	Europe	Sustainability, including energy and carbon, food security, business resilience	http://www.sustainfarm.eu/en/decision-support-tool
The EX-Ante Carbon-balance Tool (EX-ACT)	English	No cost	Audit	None specified	GHG emissions	https://www.fao.org/in-action/epic/ex-act-tool/suite-of-tools/ex-act/en/
The Regenerative Agriculture Revolution	English	? Future Learn pricing?	Course / Transition	None specified	Farm management	https://www.futurelearn.com/courses/the-regenerative-agriculture-revolution
WatchITgrow	English	?	Information, data collation	Belgium	Crop management	https://watchitgrow.be/en

APPENDIX 2 : TASK 1.1 EVALUATION OF USER NEEDS – FARMER SURVEY

Participant information sheet

Value4Farm

Dear Participant,

Value4Farm - Sustainable renewable energy VALUE chains for answering FARMers needs

More and more farmers are getting involved in the production of biofuels and energy to substitute for oil and to increase their income. Value4Farm is a consortium of 14 partner organisations across Europe enhancing the opportunities for producing electricity and biogas on farms. We have received funding from the European Union's Horizon Europe research programme to undertake this work.

We are inviting you to take part in this important project. To capture the current situation, we are seeking the help of farmers and landowners from a national spread of farm businesses in *insert country name*. The *insert partner name* are administering this survey and the data will be analysed by our partner, the University of Reading, UK.

This questionnaire has been designed to take no more than 15 minutes to complete. The search for alternative, sustainable and cheaper energy/fuel is crucially important and by taking part you will be making a direct contribution to the creation of effective policies and sound advice suitable for farmers such as you. There will be opportunities for you to engage further with the project and benefit from the knowledge exchange platform we are creating.

The enclosed questionnaire has two parts:
A. Questions about you and the farm business
B. Questions to determine whether renewable energy production would suit your farm and whether you would consider becoming involved.

Terms of Participation

The data will be kept on a password protected computer until analysis. If you change your mind and want to remove your data, please contact s.edwards@reading.ac.uk by 31 January 2024. For all subsequent analyses, all participant data will be anonymised and you will not be identifiable. The findings will be reported at conferences, in technical reports and academic journals in anonymised form only. Finally, all personal data will be deleted on 30 June 2024.

This project has been reviewed and approved by the University of Reading's Research Ethics Committee. Please confirm your consent to being part of our survey by entering a unique identifier of your choice below (for example a memorable word).* This will allow us to withdraw your data anonymously, should you request it.

We do hope you will be able to find time to answer our questions. If you do so we will be very grateful.

Survey questions - Contextual information on the farm and farmer

If possible, we would like the main decision-maker to answer this. So that we can get some idea of what sort of farm business you are involved in, please tell us about your current situation (i.e. 2023 harvest year, area data can be approximate):

1. What country are you based in?

2. What is your nearest large town or city?

3. Total area farmed ______ ha

of which consists of:

Cereals	ha
Other arable crops	ha
Grass Leys	ha
Permanent pasture and rough grassland	ha
Horticultural field crops, other than roots	
Root crops	
Horticulture under glass	ha
Specific crops grown for biomass energy*, ie maize	ha

and under what arrangements:

Owner-occupied	ha
Rented on long-term agreements	ha
Rented on other arrangements	ha
Share farmed	ha
Other	ha

4. If you have livestock please indicate current livestock numbers: if not go to question 5

Dairy cattle		Pigs	
Beef cattle		Poultry	
Sheep		Other livestock (please specify)	

5. Please tick if any of the following apply:

The majority of my production is registered organic	
I farm in a high nature value area	
I sell products to the public directly from the farm	
I sell side streams off farm [ie straw and manure]	
I have undertaken a carbon audit of the farm	
I am involved in trading carbon credits	

I sell products to other businesses	

6. What percentage of your time do you spend managing and working on your farm? [%]

7. Total number of regular workers including you and your family: Full-time [ ] Part-time [ ]

8. Your age: [ ]

9. Your gender: woman [ ] man [ ] non-binary [ ] prefer not to say [ ]

10. Have you identified a successor? Definitely [ ] Very likely [ ] Possibly [ ] Unlikely [ ] Definitely not [ ]

11. The age you left full-time education: [ ]

12. Approximately what proportion of the income of **your household in a typical year** comes from sources other than farm business?
[%]

13. In terms of business viability please indicate which of the following statements is most accurate:

At the moment my business is not profitable and may not survive	
At the moment my business is not profitable but can survive for at least 5 years	
Profits are down, but my business should be able to survive	
I maintain a steady profit level	
I am increasing my profit level	

14. Are you a member of a co-operative?
Yes [ ] No [ ]

If yes, please tick which of these:

Selling cooperative	
Buying cooperative	
Training cooperative	
Energy related cooperative	
Other	

If other, please stipulate

Survey questions - Energy use and current production

13. Is your farm attached to the national grid for?

Yes No

a) Gas ☐ ☐

b) Electricity ☐ ☐

c) Heat ☐ ☐

14. Do you produce any of your own energy to help meet your needs? If yes, please tick:

Wind turbine electric	
Solar panels on buildings and non-productive land	
Solar panels on previously cultivated land or grassland	
Solar panels on currently cultivated land or grassland	
Gas production from biogas plant	
Combined Heat and Power	
Heat from biomass	
Geothermal energy	
Hydrothermal energy	
Other	

If other, please specify____

15. Do you export electricity, gas or biomass off the farm? If yes, please tick:

	Yes	No
Gas		
Electricity		
Biomass for energy		

16. Do you use on farm gas production to power farm machinery?

Yes ☐ No ☐

If yes, approximately what proportion is derived from gas: [%]

17. Do you produce any surplus waste products from crop or animal production that you feel could be potentially used For energy production?

Yes ☐ No ☐ If yes, please tick:

Manure		Root crop waste	
Surplus straw		Woody products	
Green crop waste		Other	

If other, please specify: ____

18. Please can you state (if you know it) your approximate use of energy?

KW

19. Please estimate the proportion of your total farm business costs that is related to energy purchase:

KWh

20. Please indicate your main use of diesel fuel, gas and electricity. Please tick top three uses of each:

	On-farm operations (sowing, planting, etc.)	Irrigation	Energy use in barns and farm buildings	On-farm post-harvest operations (storage, grain drying)	Horticultural production e.g. heating glasshouses	Waste management
Diesel fuel						
Gas						
Electricity						

Survey questions – Interest in energy related diversification/production

21. Are you considering investing in energy diversification on your farm in the next 5 years? Please tick:

Yes ☐ No ☐

22. If yes, please tick, which of the following possibilities apply:

Wind turbine electric	
Solar panels on buildings and non-productive land	
Solar panels on previously cultivated land or grassland	
Solar panels on currently cultivated land or grassland	
Gas production from biogas plant	
Combined Heat and Power	
Heat from biomass	
Geothermal energy	
Hydrothermal energy	
Other	

If other, please state: ___________________________________

23. Would any of the following factors encourage you to move towards implementation of on-farm renewable energy production? Please tick which of the following apply:

Provision of grant funding		Insecurity of supply from the grid	
Provision of low interest loans		Environmental pressures	
More information and advice		Increased local uptake by other farmers	

More demonstration farms		Creation/presence of Co-ops	
Further increases in energy costs		Other	

If other, please state: ______________________

24. Please indicate how important the following are when considering producing electricity and biogas on your farm:

	Very important	Important	Not very important	Of little importance	Extremely unimportant
The returns needed for a good financial return					
Affordable establishment costs					
A personal understanding of the technology					
The need for no additional labour					
Impact on any tenancy agreements					
Simplicity of obtaining planning permission					
A technology that would not impact my current farming system					
Easily available information and support					
Other. Please state:					

25. How important would the following benefits of producing electricity and biogas on farms be to you?

	Very important	Important	Not very important	Of little importance	Extremely unimportant
Improve farm profit					
Reduce pollution					
Reduce the farm's carbon footprint					
Provision of better security of energy supply					
Easy integration within my current system					
Improved use of current residues					
Improved sustainability of my business					
Other. Please state:					

Survey questions – Training and knowledge needs

26. Please indicate below how important future training in the following areas would be to you:

	Very important	Important	Not very important	Of little importance	Extremely unimportant
Diverse crop rotations					
Agrivoltaics					
Wind Power					
Anaerobic digestion					
Other – please specify:					

27. What is your preferred format for training and knowledge materials? Please tick as appropriate:

Audio	
Video	
Paper based	
In-person workshops/demonstrations	
Online workshops/demonstrations	
Other. Please state:	

Survey questions – Future contact with the project

Subscribe to Value4Farm newsletter to keep posted about the latest progress and activities of the project!
http://eepurl.com/iBXOy6

Would you like to join an End Users Advisory Board?

We are calling on farmers to join an Advisory Board whose role will be to provide feedback on the progress of the Value4Farm project. We will be holding several online board meetings to present and discuss the results and invite you to site visits and the Value4Farm final workshop. If you are interested, please provide your email address in the box below. This email address will be stored separately from your questionnaire responses.

Appendix 3: Focus Group Protocol

Objectives

A round of consultations and in person meetings with **a small number** of **farmers** and **stakeholders** in the form of a **focus group** discussion will be used to:

- develop and order the **end-user needs** *in order to implement the cropping protocols on-farm*
- structure a set of **user stories** to support the development of the decision support tools *(OOC, Audit tool, Transition tool)*
- *explore in more depth some of the results from the farmer questionnaire*

Aim

To refine the cropping protocols to ensure they can be implemented by farmers in each region

Participants

1. Facilitator from the project team (1)
2. Note taker from the project team (1-2)
3. Farmers (3-5)
4. Other stakeholders (2-3) e.g. energy companies, agricultural consultants, farmer organisation representatives, policy makers, local authorities, local planning authorities

Protocol for in-person Focus Group meetings

1. Facilitator read out the agenda (the meeting will last up to 120 mins)
2. Read participant information sheet and each to complete a consent form (5 mins)
3. Round table introductions (5 mins)
4. Start voice recording (using mobile phone/digital recording from MS Teams)
5. Facilitator to describe the regional protocol (provide prints outs of the cropping protocol diagrams). Allow questions/discussion to allow understanding of the whole value chain. (15 mins)
6. Conduct a SWOT analysis of each protocol – facilitator to ask participants to discuss as a group the current strengths & weaknesses [relating to own farming system], opportunities & threats [external environment] of the <u>on-farm implementation of the crop protocol as viewed by each stakeholder.</u> Note taker to write down the group's outputs in a table – (30 mins)
7. Knowledge gaps – facilitator to ask what <u>support/knowledge</u> farmers & other stakeholders need to be able <u>to implement these protocols</u> and how this information would be best delivered. Collect multiple suggestions from individuals on post it notes in the form of user stories "As a [persona], I [want to *know*], [so that]." (20 mins)

   Short break (10 mins)
8. Facilitator to explore the initial results from the farmer survey responses in more depth, for example by asking some of these questions (30 mins)
   a. Would you like to produce more of your own energy needs?
   b. What do you think are the most promising energy diversification sources [what might you do first on farm]?
   c. How might you finance energy diversification on farm?
   d. Do you think that obtaining planning permission for a digester and/or solar panels would be a problem?
   e. What would your farming neighbours or family think if you went into energy production?
9. Wrap up & thanks (5 mins)

10. Translate notes into summary form and send back to UREAD (after focus group) see examples below

Focus groups

Focus Group 1 Sustainable crop protocol for the Atlantic region

In Denmark conducted by AU

In Poland conducted by IUNG

Focus Group 2 Sustainable crop protocol for the Mediterranean region

In Italy conducted by CIB (Farmland BiogasDoneRight in scenario 3)

Focus Group 3 Protocol of good practices for handling already existing residual crop streams and use of digestate

In Belgium conducted by INA

In Iceland conducted by OKD

Focus group 1 – Sustainable crop protocol for the Atlantic pedoclimatic region (Denmark - AU, Poland - IUNG)

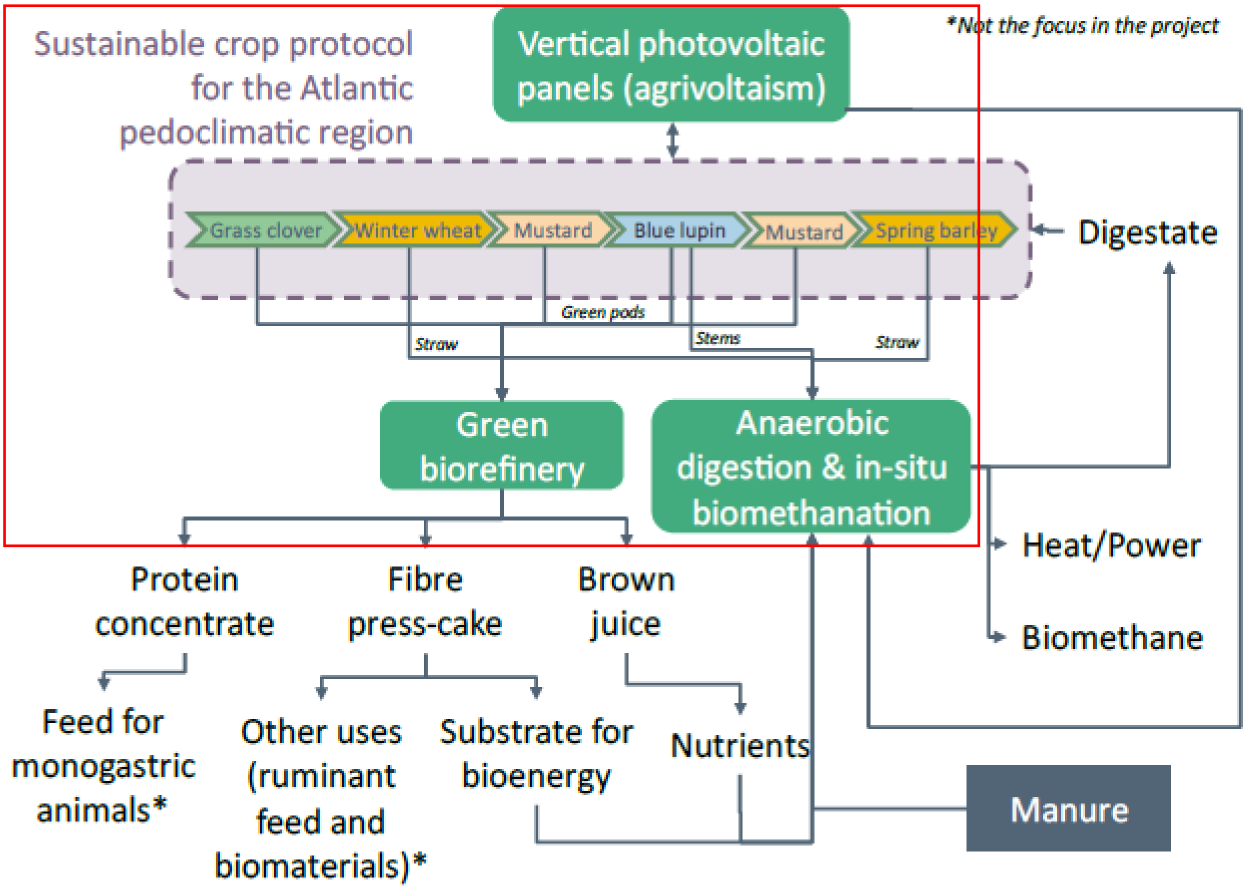

Figure A10: Protocol for Focus Group 1

The foreseen agricultural crop protocol for Denmark (and the Atlantic pedoclimatic region) is the following: *Planned rotation* (Figure 1.7): grass clover (duration: 24 months) - winter wheat (duration: 10 months) - cover crop (e.g. mustard; duration 3-6 months) - blue lupine (duration: 4 months) - cover crop (e.g. mustard; duration 3-6 months) - spring barley with a grass-clover ley.

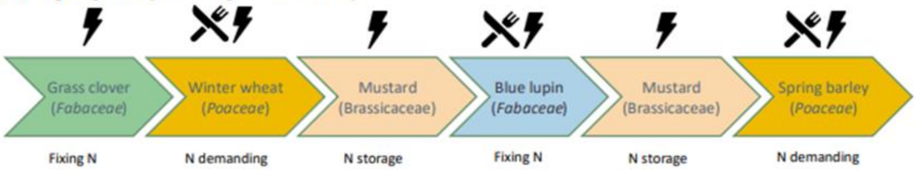

Figure 1.7: Foreseen crop rotation in Denmark

Figure A11: Cropping protocol for Focus Group 1

Ask stakeholders to conduct the SWOT analysis on the on-farm implementation of the **photovoltaic panels and highlighted crop protocol section only (in the red box)**

The main aim of this protocol is to maximise energy output per area of land for large scale farms by producing electricity from the photovoltaic panels, food/animal feed from the crops, and supplying biorefineries with waste streams for energy production.

- Novel crop protocol, including wheat as it is a common trans-European crop and legumes (e.g. blue lupin, grass clover) as nitrogen-fixing crops, and cover crops (e.g. mustard).
- The developed rotation will increase carbon capture by keeping the land green for longer parts of the season using e.g. optimised intercropping and is optimised with renewable energy production (vertical agrivoltaism, green biorefining, anaerobic digestion of straw and grass fibres).
- Aim for no overall crop yield reduction between open field and with the vertical agrivoltaic installation.
- Compatibility with other agricultural streams (e.g. manure) for recycling of nutrients
- Reuse of the produced digestate
- Reduction of the use of external chemical fertilisers up to 100 % and of crop protection products >40 %
- More detail is available in the Value4Farm proposal (page 17)

Focus Group 2 – Sustainable crop protocol for the Mediterranean region with crop rotations in scenario 3 (Italy - CIB)

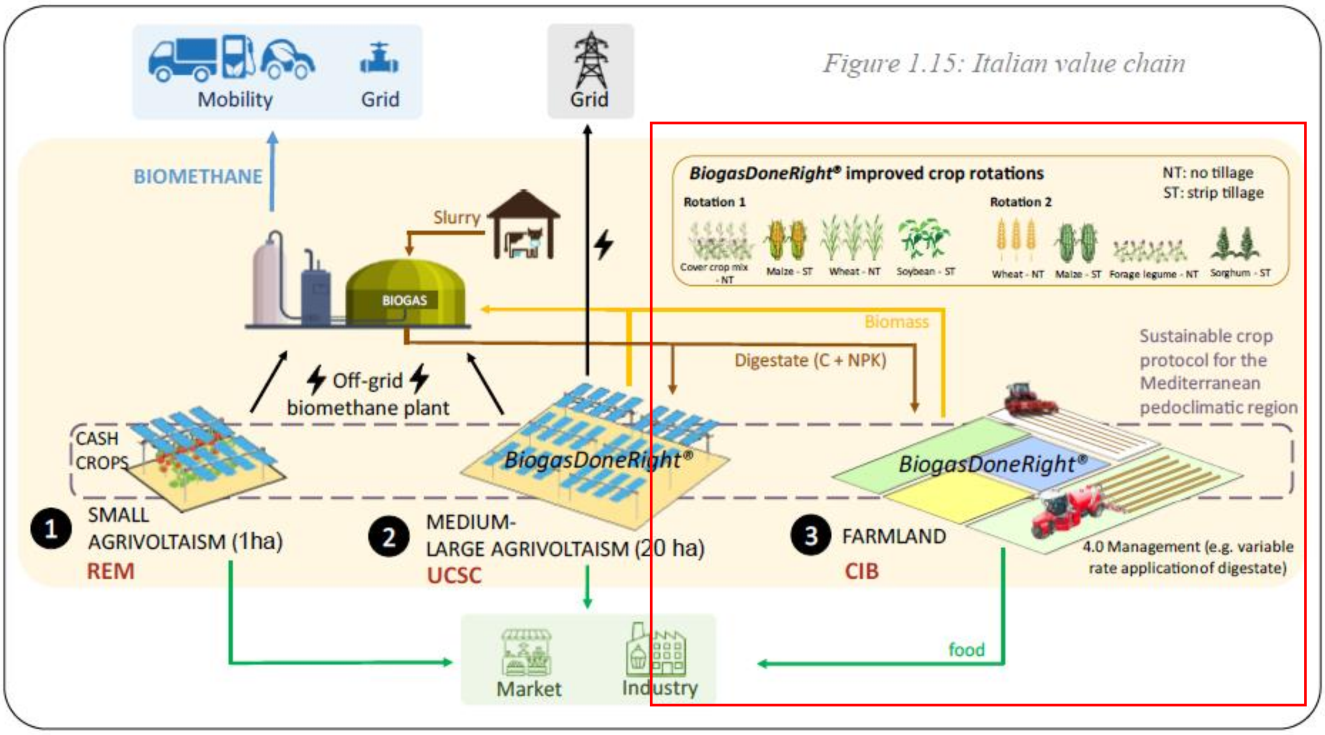

Figure A12: Protocol for Focus Group 2

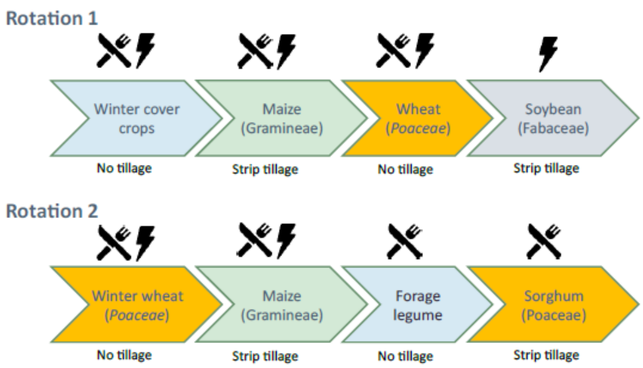

Figure A13: Cropping protocol for focus group 2

Ask stakeholders to conduct the SWOT analysis on the on-farm implementation of the **BiogasDoneRight crop rotation protocol in scenario 3 only** (highlighted in the red box)

- For larger agrivoltaic installations and for farmland of biogas farms not under agrivoltaics, the BiogasDoneRight® protocol will innovative double cropping rotations that include mix of cereals/legumes and permanent forage legumes.
- Soil and nutrient management will be managed through conservation tillage (strip tillage for summer crops and direct sowing for winter crops)
- 4.0 management of digestate use to support circularity and tighten carbon and nutrient cycle at farm level.

- Reduction of the use of external chemical fertilisers up to 100 % and of crop protection products >30 %
- More detail is available in the Value4Farm proposal (page 18)

Focus Group 3 Protocol of good practices for handling already existing residual crop streams and use of digestate (Belgium – INA, Iceland - OKD)

Ask stakeholders to conduct the SWOT analysis on the on-farm implementation of the **best practice protocols** below:

- best practices on how to handle already available biomass in high volumes (e.g. leeks, horticulture, etc.), taking into account e.g. biomass storage, machinery to be used, availability throughout the year, etc. and their costs
- Compatibility with other agricultural streams (e.g. manure) for recycling of nutrients
- Good practices for reuse of the produced digestate
- More detail is available in the Value4Farm proposal (page 19)