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AGROFOSSILFREE

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Decision Support Toolkit (update)

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Abstract

The main objective of the AgroFossilFree Horizon2020 project is to create a framework under which all core stakeholders can cooperate to evaluate and promote the currently available fossil-energy-free technologies and strategies (FEFTS) in EU agriculture in a cost efficient manner. AgroFossilFree has implemented an online and interactive approach to communication, interaction and knowledge sharing and exchanging through the use of a specifically designed ICT tool, the "AgEnergy Platform", which deploys the collected information and knowledge on FEFTS in the form of easily accessible end-user material facilitating searching through the use of filters. Still, the question remains of how can you choose which one is the most appropriate one or the most cost-effective one for each farm. The answer to that in reality comes after a detailed study on a per farm basis. An intermediate level was developed to bridge these two extremes, that can provide a first insight on which FEFTS probably suits best to each farm using minimal user inputs. This Decision Support Tool (DST) is integrated seamlessly within the AgroFossilFree platform and allows users to get a ranking of the technologies most suitable for their farm. This decision support toolkit based on Artificial Intelligence is designed and realized able to address coherently qualitative and quantitative variables. A well-established approach based on Fuzzy Cognitive Maps is implemented. First the most appropriate parameters are identified, then indicators are set for each parameter, the AI tool is developed and finally hosted on the platform. A questionnaire is developed and filled out by project's participants (at least 20 questionnaires) in order to properly map expert knowledge which will be the backbone of the tool. Essentially, the AI tool mimics the consultation process if these experts were in the same room evaluating the input data provided by the end-user to propose the most effective action. The tool is fully functional and currently online. Optimization and of course maintenance of the tool will continue until the end of the project. Finally, it has to be highlighted that a peer-reviewed paper has been accepted for publication in Smart Agricultural Technology journal (Elsevier) presenting the approach followed and the actual tool, which can be accessed at https://doi.org/10.1016/j.atech.2022.100169.

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1. Context

1.1. The AgroFossilFree project

The main objective of AgroFossilFree is to create a framework under which all core stakeholders will cooperate to evaluate and promote the currently available fossil-energy-free technologies and strategies (FEFTS) in EU agriculture to decrease in the short term and eliminate in the long run the use of fossil energy in open-field crop production and controlled environment agricultural constructions from cradle to farm gate, while maintaining yield and quality of the end product offered to consumers in a cost efficient manner. Such framework will contribute in bridging the gap between the available novel high-end clean energy solutions and the everyday European agricultural practices by capturing grassroots-level needs and ideas, promoting effective exchange of information and investigating the possible financing opportunities for any de-fossilizing activity between the farming and related industry community. Ultimately, it will facilitate farmers to find solutions for their specific needs contributing towards fossil-free farming.

Fossil-Energy-Free Technologies and Strategies (FEFTS) refers to the tools that are required to address clean energy production and use in agriculture including Renewable Energy Sources (RES), Energy Efficiency Technologies, Agricultural Constructions Management Systems, Biofuel production and use, Agricultural Machinery using biofuels, electrified implements, Smart Farming Technologies, Conservation agriculture methods and Best Energy Management Practices for rational use of energy and reduced GHG emissions. The benefits of FEFTS are related to cleaner and more efficient energy production and use, resulting in economic, agronomic and environmental benefits. Stakeholders and end-users in the value chain have different needs with regards to FEFTS for agriculture. Arable farming, orchards, vineyards, open-field vegetables, greenhouses and livestock facilities are the agricultural subsectors, where energy is extensively used to maintain acceptable production levels. AgroFossilFree addresses agricultural energy needs, allowing farmers to optimize agricultural production.

1.2. FEFTS types

In line with work performed in Work Package 2 and presented in Deliverable 2.1 Report on methodology and standards the four level of specification of FETS are presented in Table 1. The work on this deliverable builds upon this specification in order to be fully in line with it both content-wise but also programming-wise.

Table 1. four levels of specifications of FEFTS

Question	Question	Answer
A	What kind of agricultural technology applications is it for?	✓ *Heating and cooling of agricultural constructions* ➔ *Stables* ➔ *Greenhouses* ➔ *Farmer's buildings* ➔ *Cultivations (small scale construction, nylon)* ✓ *Process heat/cold* ➔ *Drying of commodities* ➔ *Pre-processing of agricultural goods* ➔ *Hygenisation* ➔ *Cold storages* ✓ *Lighting* ➔ *Architecture using daylight* ➔ *Energy efficient light bulbs* ✓ *Agricultural field practices* ➔ *Tilling/ploughing* ➔ *Planting/seeding* ➔ *Fertilizing* ➔ *Pest control (crop protection)* ➔ *Irrigation* ➔ *Harvesting* ✓ *Vehicles* ➔ *Electric tractors* ➔ *Biogas/biomethane tractors* ➔ *Biodiesel/PPO tractors* ➔ *Combine harvester* ➔ *Trailers and tractor tools* ➔ *Wheel-loaders* ✓ *Tools* ➔ *Milking robots* ➔ *Feeding robots* ➔ *Conveyors*

		➔ *Mills/grinders* ➔ *Dryers* ✓ *Energy sales to external consumers* ➔ *Solid biomass* ➔ *Biogas/biomethane* ➔ *Bioliquids* ➔ *Crops* ➔ *Electricity feed-in* ✓ *Heat sales to District Heating*
B	What is the type of FEFTS?	✓ *Clean Energy Production (Questionnaire moves to Question C)* ✓ *Energy Efficiency Improvement (Questionnaire moves to Question D)* ✓ *Soil Carbon Sequestration (Questionnaire moves to Question E)*
C	What type of system is this FEFTS?	✓ *Energy Production System (Questionnaire moves to C1, C2 and C3)* ✓ *Energy Storage System (Questionnaire moves to C4)*
C1	What Type of Renewable Energy Source does it use?	✓ *Solar* ✓ *Wind* ✓ *Hydro* ➔ *Kinetic* ➔ *Potential* ✓ *Biomass* ➔ *Pellets* ➔ *Woodchips* ➔ *Logwood* ➔ *Energy crops* ➔ *Agricultural residues* ✓ *Landfill gas* ✓ *Sewage treatment plant gas and biogases* ✓ *Geothermal*

		➔ *Solid/ground* ➔ *Fluids* ✓ *Aerothermal* ➔ *Ambient air* ✓ *Hydrothermal* ➔ *Groundwater* ➔ *Water bodies* ✓ *Marine energy* ➔ *Wave energy* ➔ *Tidal energy*
C2	What is the energy type that it produces?	✓ *Heating* ➔ *Heat for agri-processes* ➔ *Buildings* ✓ *Cooling* ➔ *Cooling for agri-processes* ➔ *Cooling for buildings* ✓ *Electricity* ➔ *AC* ➔ *DC* ✓ *Mechanical energy* ➔ *Stationary applications* ➔ *Mobile applications* ✓ *Chemical energy* ➔ *Gaseous fuels* ➔ *Liquids fuels* ➔ *Solids fuels*
C3	What is the specific technology used to produce this type of energy?	✓ *Photovoltaics* ➔ *PV-arrays* ➔ *Agri-PV systems* ➔ *PV on tools and vehicles* ✓ *Solar thermal* ➔ *Flat plate collectors* ➔ *Evacuated tube collectors*

- ➔ *Concentrated*
- ➔ *Thermosiphon systems*
- ➔ *Photovoltaic and thermal collectors (PVT)*
- ➔ *Ground mounted solar collectors*
- ✓ *Wind turbines*
- ➔ *Small wind turbines (1-50 kw)*
- ➔ *Medium wind turbines (50-999 kw)*
- ➔ *Large wind turbines (<1 MW)*
- ➔ *Water wind pumps*
- ✓ *Hydropower*
- ➔ *Micro (1-10 kw)*
- ➔ *Mini (10-100 kw)*
- ➔ *Small (100-1000 kw)*
- ➔ *Run-of-the-river*
- ✓ *Heat pumps*
- ➔ *Ground source heat pump*
- ➔ *Water heat pump (surface and ground water)*
- ➔ *Ambient air heat pump*
- ➔ *Other heat pumps*
- ✓ *Geothermal*
- ➔ *Shallow geothermal (until 400 m)*
- ➔ *Deep geothermal (deeper than 400 m)*
- ✓ *Solid biomass conversion*
- ➔ *Woodchip boilers*
- ➔ *Wood log boilers*
- ➔ *Pellet boilers*
- ➔ *Woodchip gasifiers (CHP)*
- ➔ *Pellet gasifiers (CHP)*
- ✓ *Biogas / biomethane production*
- ➔ *Anaerobic digestion technologies*
- ➔ *Bio methane upgrading technologies*
- ✓ *Liquid biofuels production*
- ➔ *Oil presses*

		➔ *Biodiesel plants* ➔ *Distilleries*
C4	What type of energy storage system is?	✓ *Heat storage* ➔ *Buffer tanks* ➔ *Seasonal heat storage systems* ➔ *Latent heat storages (pcm)* ➔ *Thermo-chemical storages* ✓ *Electricity storage* ➔ *Lithium-ion batteries* ➔ *Redox flow batteries* ➔ *Zinc-hybrid batteries* ➔ *Lead–acid batteries* ➔ *Hydrogen (subsystem)* ✓ *Cold storage* ➔ *Ice/slurry storage systems* ➔ *Other cold storage systems* ✓ *Intermediate bioenergy carriers* ➔ *Pellets* ➔ *Wood chips* ➔ *Wood log* ➔ *Torrefied biomass* ➔ *Charcoal* ➔ *Oils* ✓ *Other intermediate bioenergy carriers*
D	What kind of energy efficiency improvement is it?	✓ *Efficient buildings* ➔ *Building wall insulation* ➔ *Roof insulation* ➔ *Cellar insulation* ➔ *Windows* ➔ *Building management systems* ➔ *Efficient lighting* ✓ *Efficient vehicles* ➔ *Maintenance (e.g. Tyre pressure)*

		➔ *Logistics/planning* ✓ *Efficient tools* ➔ *Irrigation (pumps, drip systems etc)* ➔ *Conveyors* ➔ *Milking machines* ➔ *Refrigerators* ➔ *Feeding* ✓ *Precision agriculture* ➔ *Seed reduction* ➔ *Fertilizer reduction* ➔ *Pesticide reduction* ➔ *Lime reduction* ➔ *Manure reduction* ➔ *Water reduction* ✓ *Precision livestock farming* ➔ *Feed reduction* ➔ *Medicine reduction* ➔ *Animal healthcare* ➔ *Manure reduction* ✓ *Conservation agriculture* ➔ *Crop rotation* ➔ *Soil coverage* ➔ *No/minimum-tillage* ✓ *Efficient postharvest technologies*
E	Which carbon sequestration technique is used?	✓ *Soil organic matter* ➔ *Terra preta* ➔ *Compost* ➔ *Harvest residues* ✓ *Tillage (conservation agriculture + CTF)* ✓ *Nutrient management* ✓ *Crop diversification* ✓ *Soil and water conservation techniques* ✓ *Fire management*

✓ *Grassland management*

1.3. AgroFossilFree Platform

AgroFossilFree has implemented an online and interactive approach to communication, interaction and knowledge sharing and exchanging through the use of a specifically designed ICT tool, the **"AgEnergy Platform"**, which will deploy the collected information and knowledge on FEFTS in the form of easily accessible end-user material following the EIP-Service Point format[1].The AgEnergy Platform will be the tool for online assessment of the inventoried FEFTS by stakeholders across Europe, will allow for the crowdsourcing of grassroots-level ideas and needs for research

1.4. Why a decision support toolkit?

A user visiting the AgroFossilFree platform will find a wealth of information regarding FEFTS. The website is developed having user experience at its core. The filters that can be applied can be used in many combinations in order to reveal the FEFTS database's content that is stored on the platform. Still, how can you choose which one is the most appropriate one or the most cost-effective one. The answer to that in reality comes after a detailed study on a per farm basis. But we wanted to develop an intermediate level, a level that can provide a first insight on which FEFTS probably suits best to the need be integrated seamlessly within the AgroFossilFree platform and allow users to get a ranking of the technologies most suitable for each farm. If 10 agricultural experts are in the same room, they could have a discussion given a minimum amount of info and could be based on experience highlight the FEFTS with most applicability to the farm at hand. This would act of course only as the first step in study process that would evaluate different options and provide the optimal investment for each farm. The consortium decided to use Artificial Intelligence to provide this first step that goes beyond an advanced database search. The Decision Support Toolkit will be integrated seamlessly within the AgroFossilFree platform and allow users to get a ranking of the technologies most suitable for each farm. In reality the tool represents the collected knowledge of at least 20 experts working in the consortium and beyond. The knowledge is collected through questionnaires and essentially, the AI tool will mimic the consultation process if these experts were in the

[1] Guidelines on Programming for Innovation and the Implementation of the EIP. Programming period 2014-2020.Version July 2014.

same room evaluating the input data provided by the end-user to propose the most effective action.

2. Theoretical background

2.1. Decision Support Systems

Decision making is an inherently human activity. Decisions span the whole spectrum of human activity and as such it is not surprising that numerous researchers have tried to improve the quality of decisions in different fields by providing tools to support the decision-making process. Further to that effort has been made to develop computer-based technologies that can augment and extend human capabilities. The development of Artificial Intelligence tools has found application in decision support systems in many sectors like finance, healthcare, marketing, commerce, command and control, and cybersecurity. The term intelligent refers to systems aiming at mimicking human cognitive capabilities to an extent and the decision support systems employing such technologies have been referred to as Intelligent Decision Support Systems (IDSS)[1].

IDSS utilize Artificial Intelligence paradigms to reason, learn, remember plan and analyze. Decisions are referred to as structured, unstructured or semi-structured depending on the degree of certainty of the problem representation and solution. The decision making process described by Simon [2] is generally accepted by researchers who develop DSS as consisting of four phases:

1. **Intelligence:** the decision maker gathers information and develops an understanding of the problem
2. **Design:** the decision maker identifies criteria, develops the model and investigates alternatives
3. **Choice:** a selection or decision is made
4. **Implementation:** The decision maker acts on the decision and learns

The process is at a large extent sequential with feedback loops between phases. As mentioned before, IDSS are intelligent when they express intelligent behavior. Intelligent behavior includes among others[3, 4]:

- Learn or understand from experience;
- Make sense out of ambiguous or contradictory messages;
- Respond quickly and successfully to a new situation;
- Use reasoning in solving problems;
- Deal with perplexing situations;
- Understand and infer in ordinary, rational ways;

- Apply knowledge to manipulate the environment;
- Think and reason;
- Recognize the relative importance of different elements in a situation

AI paradigms can be utilized in all stages of a DSS implementation. These include:

- Machine learning algorithms [5]
- Neural Networks[6]
- Case based reasoning [7]
- Expert systems [8]
- Genetic algorithms [9]
- Fuzzy Logic [10]
- Intelligent Agents [11]
- Intelligent Multi-agent systems [12]
- Neural Networks [13]
- Fuzzy Cognitive Maps [14]

2.2. Fuzzy Cognitive Maps

As research has been advancing in IDSS effort has been made in bridging the gap between qualitative and quantitative models through the use of such soft computing techniques [15, 16]. Qualitative variables can be expressed through the use of linguistic variables. The linguistic variables in turn can be expressed by fuzzy sets. The quantitative variables can also be expressed by fuzzy sets, with emphasis given to their uncertainty [15]. Fuzzy cognitive maps (FCM) are able to deal with processes like decision making that is based on human reasoning process [17]. Because of this, FCMs have been used successfully in different fields. Many applications have been presented in the medical field [18, 19], in agricultural applications [20, 21], in environmental applications [22] and in energy applications [14, 23].

Decision support systems can be represented through FCMs. FCMs are graphs which represent cause and effect relationships and are used for computational inference processing [24]. Systems can be symbolically represented through FCMs. Concepts are used to present different aspects of the modeled system such as inputs, outputs, rules or intermediate states.

$$C_i,\ i = 1, \ldots, N$$

where N is the total number of nodes.

The value of each concept is fuzzified in the space [0,1].

$$A_i \in [0,1], i = 1,...,N$$

These node-concepts are interconnected with arcs which have different weights in order to express their relations. One FCM is depicted in Figure 1.

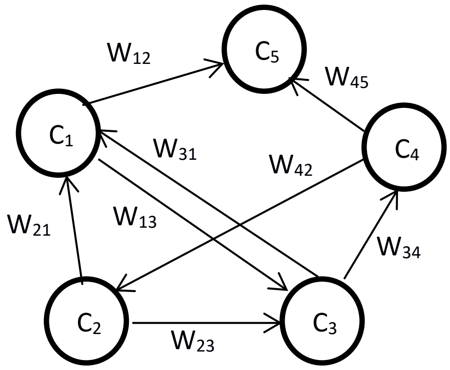

Figure 1. A Fuzzy Cognitive Map

In order to give values to the weights human knowledge and experience is used. The weights are:

$$W_{i,j} \in [-1,1], \; i = 1,...,N \text{ and } j = 1,...,N$$

When the weight expresses positive causality, the weight is positive, when the weight expresses negative causality, it is negative and zero declares no relation between the concepts. The weights can be presented in a matrix as below:

$$W_{i,j} = \begin{pmatrix} W_{11} & W_{12} & W_{13} & W_{14} & W_{15} \\ W_{21} & W_{22} & W_{23} & W_{24} & W_{25} \\ W_{31} & W_{32} & W_{33} & W_{34} & W_{35} \\ W_{41} & W_{42} & W_{43} & W_{44} & W_{45} \\ W_{51} & W_{52} & W_{53} & W_{54} & W_{55} \end{pmatrix}$$

This matrix can be simplified by substituting the weights of the Concepts which present no relation with zeros.

$$W_{i,j} = \begin{pmatrix} 0 & W_{12} & W_{13} & 0 & 0 \\ W_{21} & 0 & W_{23} & 0 & 0 \\ W_{31} & 0 & 0 & 0 & 0 \\ 0 & W_{42} & 0 & 0 & W_{45} \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

According to Kosko [25] the values of the concepts are influenced by the rest concepts according to equation 1. The FCM reaches a converged state after a number of iterations.

$$A_i(k+1) = f\left(A_i(k) + \sum_{\substack{j=1 \\ j \neq i}}^{n} W_{ji} A_j(k) \right)$$, (EQ 1)

where:

k is the iteration counter.

Function f is the activation function. Four functions have been proposed: the sigmoid function, the hyperbolic tangent function, the step function and the threshold linear function [26].

- The sigmoid function is presented in EQ 2 where $c \in (0,+\infty)$ is a steepness parameter. For a small c value (e.g., c=1) it approximates a linear function and for large values (c=10) it approximates a discrete function [26].

$$f(x) = \frac{1}{1+e^{-cx}}$$ (EQ 2)

- The hyperbolic tangent function is presented in EQ 3. It maps its output in the range [-1,1] for a c value close to 5 [26].

$$f(x) = \frac{e^{cx} - e^{-cx}}{e^{cx} + e^{-cx}}$$ (EQ 3)

- The step function is presented in EQ 4. In order to decrease the subjectivity of the of the step function a value of T equal to 0.5 is proposed [26].

$$f(x) = \begin{cases} 0 & if \quad x \le T \\ 1 & if \quad x > T \end{cases}$$ (EQ 4)

- The threshold linear function is a derivative of the step function and is presented in EQ 5 [29].

$$f(x) = \begin{cases} 0 & if \quad x \le T \\ (x-T) & if \quad x > T \end{cases}$$ (EQ 5)

According to [26] the sigmoid function presents specific advantages than the other concepts. Also, the needed output needs to be mapped in the space [0,1]. This is why it has been used in many applications comparable to the AgroFossilFree one and is the choice for AgroFossilFree as well.

In order to model a process or a controller with an FCM, expert knowledge is needed.

An FCM is usually constructed by a knowledge engineer who acquires domain knowledge from systems experts and uses that knowledge to define the concepts, causal directions and linguistic variables of the edges of the graph. The domain experts identify of causal relationships among the concepts and estimate of causal link strengths with linguistic variables [19] .

Experts decide on the important aspects of the system which become the concepts and the weights are set according to the interrelations of the concepts [27]. Linguistic variables can be used by the experts in order to express the relations of the concepts in a simplified way. First of all, negative, positive or no causality is set. After that the influence is described with variables like very weak, weak, strong, very strong etc. [24].

Due to the flexibility and versatility of FCM, along with the very good matching with the application at hand, it was decided to utilize them in AgroFossilFree Decision Support System (AFF DST).

3. AgroFossilFree DST

3.1. Design

In order to design the AFF DST, at first all the parameters that affect the decision were investigated and are presented. Then for each parameter corresponding indicators were selected. These indicators are in essence the inputs of the AFF DST. An FCM approach was chosen based on its ability to address coherently qualitative and quantitative variables. The FCM, which is the backbone of the approach, is designed and its parameters are set by experts, along with the fuzzification and defuzzification functions.

3.2. Implementation methodology

The methodology approach followed for the implementation of the AFF DST consists of four discrete stages:

Stage A: Parameters' identification.

All the parameters that can affect the evaluation of FEFTS are investigated and presented. The parameters are broken down in five distinct categories; legal/ regulative/ administrative, financial, technical, social and environmental and climate action. The chosen parameters are the result of interviews with experts and stakeholders.

Stage B: Indicators' choice.

The parameters that were chosen in Stage A need to be assessed. Relevant indicators are selected from OECD, FAO, International Energy Agency, Eurostat and international literature [35].

Stage C: FCM implementation.

Based on the results of Stages A and B the FCM used to evaluate the investment is designed and its parameters are set.

Stage D: Implementation of the AFF DST.

The AFF DST is integrated with the AgroFossilFree platform.

3.3. Stage A: Parameters' identification

3.3.1. Legal/ regulative/ administrative context (P1)

P1.1 Licensing burden

A number of Whether licenses, permits, contracts, certificates etc. could be required in order to employ a FEFTS. This parameter investigates whether any licenses are needed and also the difficulty related to obtaining them (this parameter focuses on effort required).

P1.2 Coherence with EU defossilization policies and binding targets

This parameter investigates the extent each FEFTS contributes to EU policies targeting defossilization.

P1.3 Level of bureaucracy involved in deploying the investment.

This parameter investigates how time consuming is the deployment of a FEFTS. For example, in order to produce biogas and sell electricity to the grid, you need a number of licenses and permits which also take time to get. Contrary if you decide to invest in a heat pump, you simply have to decide on which heat pump to get and then it is a matter of installation only. This parameter focuses on the time required.

3.3.2. Financial context (P2)

P2.1 Investment appraisal

This is related to the predicted profitability of the investment. This parameter investigates the extent a FEFT can have on the farmer's income.

P2.2 Access to financing

This is related to the ease of obtaining financing for the investment and can include subsidies, low interest financing, loans, etc.

3.3.3. Technical Context (P3)

P3.1. Technology potential based on location

This investigates the fitting of the technology to the location. For example, PVs and Solar Thermal applications have an increased technical potential going from North to South in the EU.

P3.2 Technical applicability

This parameter is related to the maturity of the FEFTS. More mature technologies have lower risks in relation to the expected outcome. New products and technologies that have not been evaluated for longer periods of time can present a high risk.

P3.3 Location constraints

The distance from the road network and electricity grid can play a role for the deployment of some FEFTS.

3.3.4. Social context (P4)

P4.1 Social acceptability

Some FEFTS can be more acceptable than others and there are cases of false perceptions in local communities.

P4.2. Creation of new jobs

Depending on the FEFTS evaluated there can be an increase or decrease of jobs or it might not affect jobs at all.

P4.3 Distress factors (e.g., noise, shadowing / odors etc.)

There are some factors that can objectively cause distress to the local population, because of the operation of a RES investment and should always be considered by the investor.

P4.4 Education impact

The impact a FEFTS can have on education is multi-level and can play an important role to the investor. Visits to the site from school students can affect them in their further studies at the university or technical school in the relevant field. Also, the existence of universities located close to the installation of a FEFTS might lead to synergies for improvement and future upgrades.

3.3.5. Environmental and Climate Action context (P5)

P5.1 Land use

FEFTS for defosilizing agriculture ought not to have an impact on high productivity agricultural land. The FEFTS that can have a win-win outcome in improving agricultural yields and decreasing the carbon footprint ought to be promoted.

P5.2 Effect on wildlife / protected areas

There are many endangered species on the earth. In order to sustain our environmental heritage certain protected areas have been set [28]. Big installations in these areas ought to be prohibited. Also, the proximity of the installation in such an area is important for the investor, since animals and plants do not abide to humanly created border lines on a map. Big FEFTS Investments near protected areas should take into consideration special aspects like not cutting mobility routes of animals and so on.

P5.3 Effect on archaeological and cultural heritage sites

Big FEFTS investments are to be avoided if they are visible from such sites.

3.4. Stage B: Indicators' choice

The above parameters can provide the basis of the evaluation of RES investments. In order, though, to be able to compare different investments collectively or for specific parameters of it, common ground has to be found. This can be accomplished through the use of relevant indicators. These indicators can provide the framework for direct comparisons between different RES investments. The parameters are assessed using both of qualitative and quantitative Indicators. The quantitative indicators are based on databases of official statistical sources, GIS systems, maps, legal and administration documents, incentives, programs, procedures etc. The Qualitative Indicators are based on the expertise of different key actors such

- Farmers
- Agricultural experts
- Industrial /SME actors
- Academic institutions
- Local communities
- Environmental groups

For each of the parameters that were described in the previous section, the relevant indicators were chosen. In some occasions more than one indicator are used for a single parameter. This is implemented because of the significance of the respective parameters. The parameters along with the corresponding indicators are presented in Table 2.

Table 2. Parameters and relevant indicators

Parameter Category	Parameter	Indicator
P1. Legal/ regulative/ administrative context	P1.1 Licensing burden	I1.1. Process steps
	P1.2 Coherence with EU defossilization policies and binding targets	I1.2 Defossilization potential
	P1.3 Level of bureaucracy involved in deploying the investment.	I1.3 Lead time
P2. Financial context	P2.1 Investment appraisal	I2.1 Increase in income
	P2.2 Access to financing	I2.2 Number of tools available
P3. Technical Context	P3.1. Technology potential based on location	I3.1. Suitability of location to FEFT
	P3.2 Technical applicability	I3.2. Applicability in terms of size
	P3.3 Location constraints	I3.3.1. Distance from road network
		I3.3.2. Distance from electrical grid
P4. Social context	P4.1 Social acceptability	I4.1. Community Acceptance
	P4.2. Creation of new jobs	I4.2. # of created jobs
	P4.3 Distress factors (e.g., noise, shadowing / odors etc.)	I4.3 Distress index
	P4.4 Education impact	I4.4 Education impact index
P5. Environmental and Climate Action context	P5.1 Effect on wildlife / protected areas	I5.1 Distance from protected areas
	P5.2 Effect on archaeological and cultural heritage sites	I5.2 Visibility index from archaeological / cultural heritage sites

3.5. Stage C: FCM Implementation

A five-step procedure takes place in the development of the FCM to be used in the AFF DST.

Step 1: Definition of the inputs the user has to supply.

Step 2: Definition of concepts.

Step 3: Fuzzification of the inputs.

Step 4: Definition of weights.

Step 5: Calculation of outputs.

Depending on the main application of the FEFTS, i.e., open field agriculture, livestock production and greenhouses the FCM needs to be accordingly modified. The FEFTS categories for each application category (open field farming, greenhouses and livestock facilities) are presented in Table 3, Table 4, Table 5. It has to be highlighted that the list of FEFTS categories to be ranked was the result of extensive consultation among experts from different consortium partners.

Table 3. FEFTS categories for ranking for open field farming

No of FEFTS	FEFTS
1	PVs
2	Wind turbines
3	Electricity Storage
4	Biomass systems for local energy production (e.g., heat, CHP, polygeneration, etc.)
5	Improved agricultural practices incl. precision agriculture
6	Innovative vehicles (e.g., tractors, harvesters, etc.)
7	Energy efficient post-harvest processes (e.g., cold storage, drying, milling, threshing, etc.)
8	Conservation agriculture / carbon sequestration

Table 4. FEFTS categories for ranking for greenhouses

No of FEFTS	FEFTS
1	PVs
2	Wind turbines
3	Electricity Storage

4	Biomass systems for local energy production (e.g., heat, CHP, polygeneration, etc.)
5	Geothermal energy systems
6	Improved burners / boilers
7	Heating, cooling, ventilation incl. heat pumps
8	Energy efficient lighting
9	Intelligent Management Systems / Automation

Table 5. FEFTS categories for ranking for livestock facilities

No of FEFTS	FEFTS
1	PVs
2	Wind turbines
3	Electricity Storage
4	Waste for energy generation systems incl. biogas applications
5	Geothermal energy systems
6	Improved burners / boilers
7	Heating, cooling, ventilation incl. heat pumps
8	Energy efficient lighting
9	Intelligent Management Systems / Automation

Step 1: Definition of the user inputs.

The user inputs that are needed in order to calculate all the relevant Indicators are presented in Table 6Table 7, Table 8, depending on application category (open field agriculture, greenhouses and livestock facilities). It has to be highlighted that the final list of questions was the result of extensive consultation among experts from different consortium partners with the aim of finding the optimal balance between minimization of questions and enough data collected to provide meaningful results for the end user.

Table 6. User inputs for ranking for open field farming

No	Question	Possible Answers
1	What is the main farmed crop?	▪ Cereals ▪ Seeds ▪ Pulses ▪ Fruit ▪ Vegetable

		▪ Spices
2	What is the size of your farm?	▪ Small (farm <10 he) ▪ Medium (10 he ≤ farm < 100 he ▪ Large (farm > 100 he)
3	How big is the distance to the closest paved road?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)
4	How big is the distance to the electricity distribution grid?	▪ Small (distance <100 m) ▪ Medium (100 m ≤ distance < 1 km) ▪ Large (distance > 1 km)
5	How big is the distance from protected areas like Natura?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)
6	How big is the distance from archaeological or cultural heritage sites?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)

Table 7. User inputs for ranking for greenhouse farming

No	Question	Possible Answers
1	What is the size of your greenhouse?	▪ Small (greenhouse <0.1 he) ▪ Medium (0.1 he ≤ greenhouse < 1 he) ▪ Large (greenhouse > 1 he)
2	How big is the distance to the closest paved road?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)
3	How big is the distance to the electricity distribution grid?	▪ Small (distance <100 m) ▪ Medium (100 m ≤ distance < 1 km) ▪ Large (distance > 1 km)
4	How big is the distance from protected areas like Natura?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)
5	How big is the distance from archaeological or cultural heritage sites?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)

Table 8. User inputs for ranking for animal farming

No	Question	Possible Answers

1	What is the main farmed animal?	▪ Pigs ▪ Bovine ▪ Sheep ▪ Chicken
2	What is the size of your farm[2]?	▪ Small (< 20 hectares of utilized agricultural area) ▪ Medium (20 he ≤ hectares of utilized agricultural area < 100 he ▪ Large (hectares of utilized agricultural area > 100 he)
3	How big is the distance to the closest paved road?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)
4	How big is the distance to the electricity distribution grid?	▪ Small (distance <100 m) ▪ Medium (100 m ≤ distance < 1 km) ▪ Large (distance > 1 km)
5	How big is the distance from protected areas like Natura?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)
6	How big is the distance from archaeological or cultural heritage sites?	▪ Small (distance <1 km) ▪ Medium (1 km ≤ distance < 5 km) ▪ Large (distance > 5 km)

Step 2: Definition of concepts.

Two types of concepts are going to be used in the proposed FCM; input and output concepts. The output concept will be the overall evaluation for each FEFTS category as presented in Table 3Table 4Table 5. Input concepts were comprised of both the user inputs, as well as inputs calculated from data found in relevant laws, publications, simulation software packages etc. The approach underwent extensive consultation among experts from different consortium partners.

Table 9. Input concepts for open field farming

Concept	Concept

[2] The approach used by EUROSTAT based on utilized agricultural area was adopted. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Small_and_large_farms_in_the_EU_-_statistics_from_the_farm_structure_survey&oldid=406560

No	
C1	Licensing Burden
C2	Defossilization Potential
C3	Time needed from decision until the investment is operational
C4	Income increase
C5	Financing ease
C6	Suitability depending on cultivation
C7	Suitability depending on farm size
C8	Distance from road
C9	Distance from Grid
C10	Wildlife impact
C11	Archaeological impact
C12	Social Acceptance impact
C13	New Jobs impact
C14	Distress impact
C15	Education impact

Table 10. Input concepts for greenhouse farming

Concept No	Concept
C1	Licensing Burden
C2	Defossilization Potential
C3	Time needed from decision until the investment is operational
C4	Income increase
C5	Financing ease
C6	Suitability depending on greenhouse size
C7	Distance from road
C8	Distance from Grid
C9	Wildlife impact

C10	Archaeological impact
C11	Social Acceptance impact
C12	New Jobs impact
C13	Distress impact
C14	Education impact

Table 11. Input concepts for animal farming

Concept No	Concept
C1	Licensing Burden
C2	Defossilization Potential
C3	Time needed from decision until the investment is operational
C4	Income increase
C5	Financing ease
C6	Suitability depending on animal
C7	Suitability depending on farm size
C8	Distance from road
C9	Distance from Grid
C10	Wildlife impact
C11	Archaeological impact
C12	Social Acceptance impact
C13	New Jobs impact
C14	Distress impact
C15	Education impact

Step 3: Fuzzification of the FCM inputs.

The fuzzification of the inputs is essentially a mapping of quantitative and qualitative variables in the space [0,1]. The exact process will be finalized after the expert questionnaires have been filled out. The questionnaires are presented in Annex 1.

Step 4: Definition of the FCM weights.

The definition of weights is carried out according to the methodology presented in [14]. A questionnaire was prepared to be distributed among 15 experts of this field for each farming system – not all experts filled out all questionnaires. The experts answered the questions using linguistic variables. The experts included experts from the AgroFossilFree project partners and experts from academia, who all have considerable experience in the field of FEFTS. Some experts used google forms and some others print-outs. These values are then defuzzified in the space [0,1]. Using the centroid defuzzification method the linguistic values are transformed in numerical values using the membership function presented in Figure 2.

It has to be highlighted that these questionnaires were also the base for the extended consultation that followed. For example, based on discussions held, some of the FEFTS categories initially proposed were merged and other renamed. The questionnaires are presented in Annex 1.

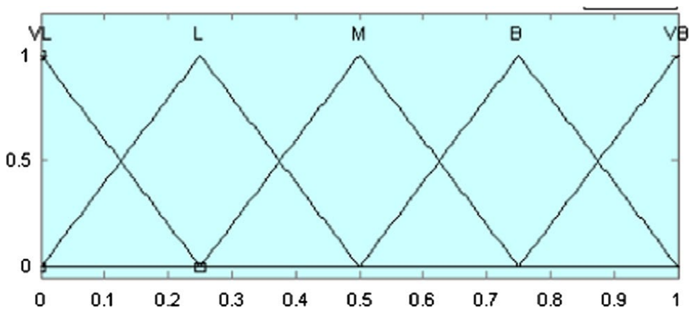

Figure 2. Membership function for the defuzzification of weights

Using this information, the Wi,j matrix that was described in Section 2.2 can be formed. In reality we have 3 main FCMs, one for each farming type category (open field, greenhouses, animal farming). The size of the farm/greenhouse as well as what is cultivated affects the weights. As such for open-field farming a total of 18 different weight sets are formed (6 farmed crops x 3 sizes of farms), for greenhouse farming 3 combinations (one for each size) and for animal farming a total of 12 (4 animals x 3 sizes of utilized agricultural area). These matrices are presented in Annex 3.

Step 5: Calculation of outputs.

By using the matrices formed in Step 4 with Equations (1) and (2) of Section 2.2, using a c parameter for Eq. (2) equal to 1, the outputs can be calculated.

The output Concepts will have a value in the space [0,1], as was described in the theoretical background of Section 2.2. As is evident, one FCM for each farming type (open field farming, greenhouses and livestock facilities) has been designed. The values of the output concepts are ranked from highest to lowest and this list presents essentially the ranking of the technologies.

4. Software implementation

It was decided for the facilitation of the tool development to follow the following Phases:

Phase A: Theoretical tool development

Phase B: Implementation of the tool in a stand-alone excel sheet, using VBA for the code.

Phase C: Implementation of the tool in the web platform.

Phase D: Integration with the AgEnergy platform.

Phase E: Public release and continuous optimization

Phase A: Theoretical tool development

This is essentially the work presented in the previous chapter.

Phase B: Implementation of the tool in a stand-alone excel sheet, using VBA for the code.

The optimization of the tool is essentially deployed in two axes:

- Optimization of the code / algorithms.
- Optimization of the actual tool.

When the first usable version of the tool was implemented, further updates in terms of the actual content and approach were still under discussion based on test use of the software. Preparing the excel sheets allowed a faster deployment for this testing. After implementing many updates such as the finalization of the FEFTS categories to be ranked in the software.

Phase C: Implementation of the tool in the web platform.

After the tool reached the release candidate state as an excel sheet, it was programmed as a web-based tool and uploaded in the web space of the AgEnergy platform to be optimized as an online tool.

Phase D: Integration with the AgEnergy platform.

The last step that remained to be realized was the seamless interconnection of the AFF DST to the AgEnergy platform. A mapping of the FEFTS categories of the AFF DST with the available FEFTS in the AgEnergy platform was realized and now through simple clicks the envisioned user experience was realized.

Phase E: Public release and continuous optimization

The tool is now online, its use is monitored and when any bug is identified, it is sorted out.

5. A typical user session

The user navigates to the AgroFossilFree AgEnergy Platform. The option is given to go to either *Browse the FEFTS solutions* using a wide range of filters or to use the *AI Decision Support Tool* by clicking the chosen link (Figure 3).

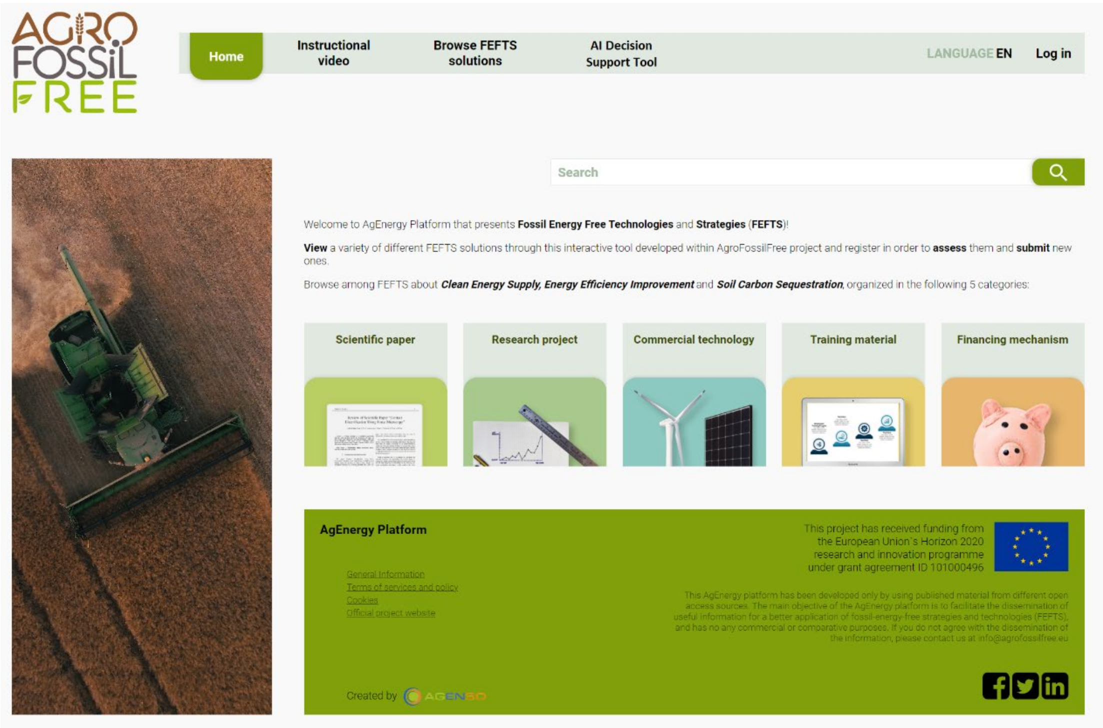

Figure 3. Main AgEnergy Platform webpage (https://platform.agrofossilfree.eu/en)

When the *AI Decision Support Tool* is chosen by the user, the new loaded page presents the 3 available choices, Open-field farming, Greenhouse farming and Animal farming, as well as the option to return to the main webpage of the platform (Figure 4).

As soon as the user makes the choice, he is navigated to a new webpage, where the user inputs presented in in Table 6Table 7, Table 8 are logged in simply through dropdown menus (Figure 5).

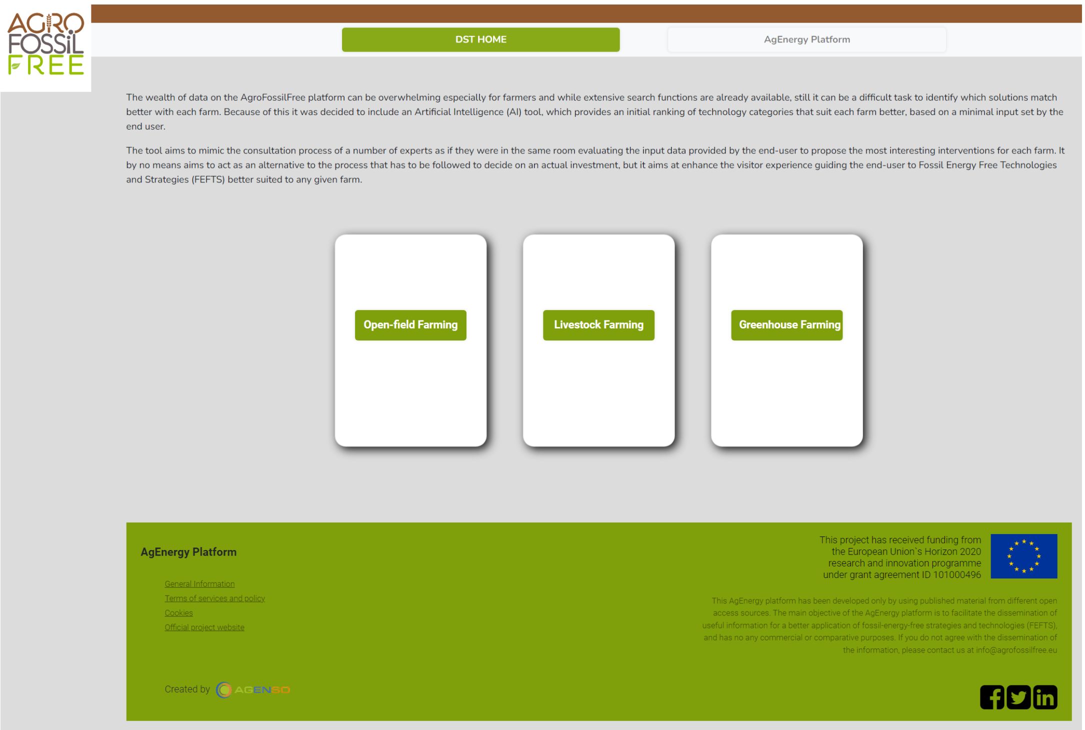

Figure 4. Main AI DST webpage (https://dst.agrofossilfree.eu/)

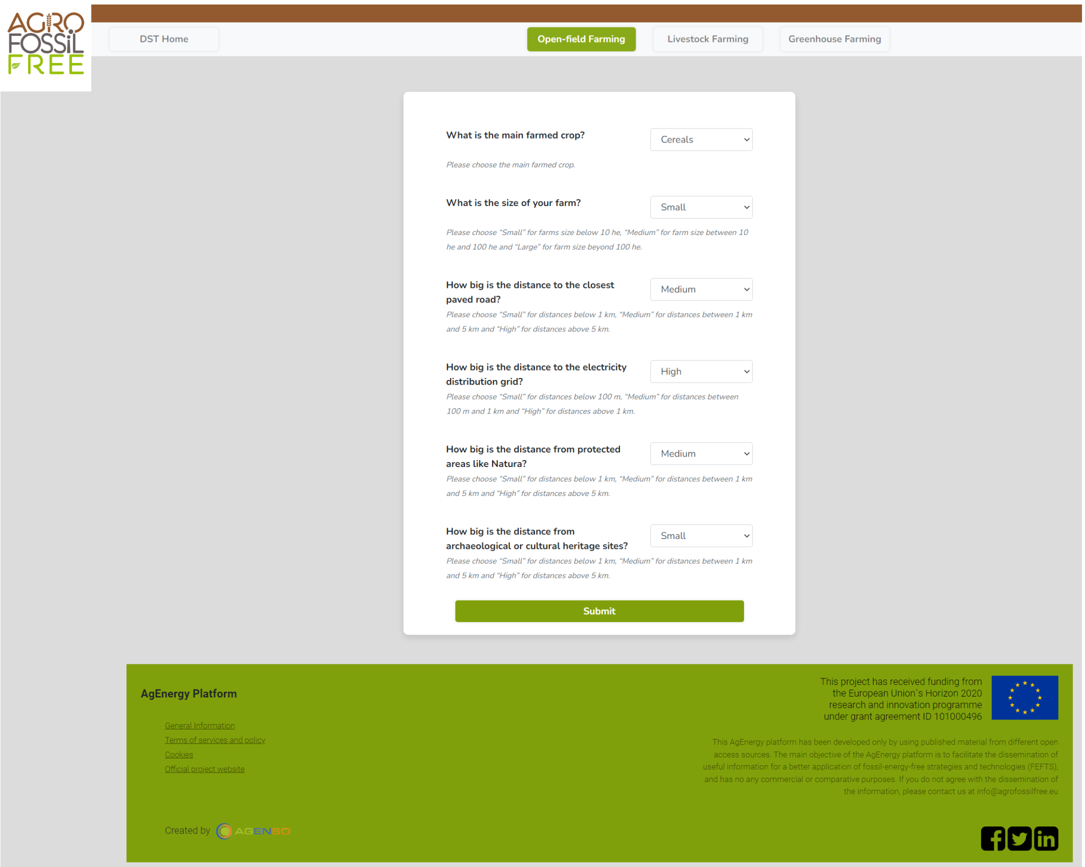

Figure 5. User inputs through drop-down menus for open-field farming (https://dst.agrofossilfree.eu/open-field)

Finally, the user is navigated to the results page. There the available FEFTS per each farming type as outlined in Table 3, Table 4, Table 5 are presented in a rank list. Moreover, for each technology a link is provided for each of the main categories of the AgEnergy platfrom database completing the functionality of the AI AFF DST. These categories are:

- Commercial Technologies
- Training Materials
- Financing mechanisms

The choice to present all FEFTS categories instead of e.g., the first three was made in order to allow the user to easily skip a FEFTS category when it does not make sense for the user's specific farm. For example if a farmer has recently invested in a new tractor and a photovoltaic system, the respective categories are simply skipped.

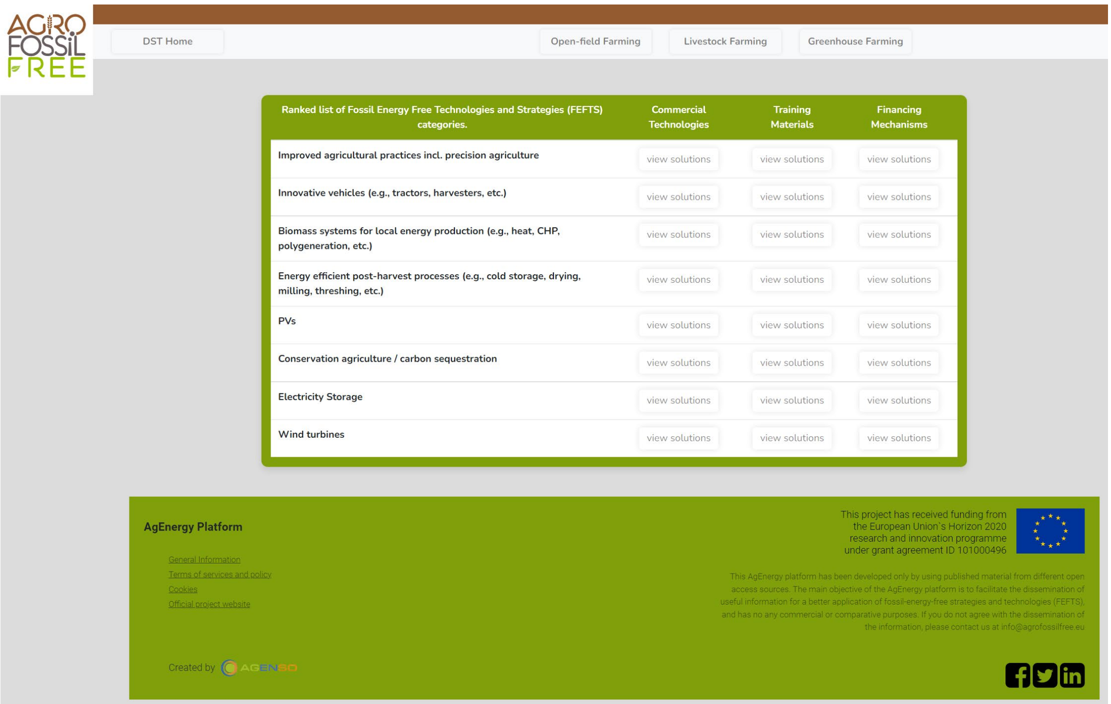

Figure 6. Results presentation

6. Conclusions

From the project inception it was clear that the target was to host a vast number of resources in the AgroFossilFree platform. The platform is equipped with a large number of filters that can be applied and can be used in many combinations in order to reveal the FEFTS database's content that is stored on the platform. The AgroFossilFree platform was made public before the AI AFF DST was implemented and comments were received from final users for possible improvements. Many farmers put forward the comment that the wealth of available information was overwhelming making it difficult for them to navigate among the numerous categories and FEFTS. This highlighted the need for a functionality such as the one envisioned to be met by the AI AFF DST Tool.

The AI AFF DST succeeds in providing a first insight on which FEFTS probably suits best to the needs of any given farm by requesting minimum inputs from the user. It cannot by any measure replace a detailed study needed in order to finally decide on an investment, but, still, it can be the first step in study process that would evaluate different options and provide the optimal investment type for each farm.

Further to this platform, the approach chosen, of using an FCM tool for providing a ranking tool based on minimal user inputs can be replicated in a vast number of comparable platforms in the agricultural sector and beyond.

Finally, it has to be highlighted that a peer-reviewed paper has been accepted for publication in Smart Agricultural Technology journal (Elsevier) presenting the approach followed and the actual tool, which can be accessed at https://doi.org/10.1016/j.atech.2022.100169.

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8. Annex 1. Questionnaires

Livestock-questionnaire.pdf Greenhouse-questionnaire.pdf Openfield-questionnaire.pdf

9. Annex 2. FCM Weights

Livestock-weights.xlsx Greenhouse-weights.xlsx OpenField-weights.xlsx