BIKE

BIOFUELS PRODUCTION
AT LOW - ILUC RISK
FOR EUROPEAN SUSTAINABLE
BIOECONOMY

D 3.2
Technology Innovation assessment of low ILUC risk system in the EU biofuels sector

Dissemination level:
PU

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1 Executive summary

The work performed in task 3.2 and reported in this deliverable has the scope to evaluate the state of development of Low ILUC risk biofuels, and which are the factors and barriers (e.g. TRL, existing policies, regulatory and financial conditions) affecting its uptake within the EU context.
To this aim, the "Technological Innovation System (TIS)" analysis is carried out. This kind of analysis provides a methodological approach to analyse and evaluate the development of a particular technological field in terms of the structures and processes that support or hamper it. The present study refers to the TIS manual developed at *Utrecht* University [1], adapted to the *BIKE project* WP3 scope.
According to the Utrecht manual, a TIS could be defined as the set of actors associated with a specific technology interacting within themselves under the influence of certain rules; thus, it is constituted of structural components, namely Actors, Networks, Institutions, Technological factors, and the dynamic interaction between them are defined through system functions.

The innovation system under investigation, namely the biofuels production at low-ILUC risk - object of BIKE project activities - consists of two Low ILUC risk biofuels value chains:

1) Value chain 1: Cultivation in unused, abandoned or severely degraded land.
2) Value chain 2: Productivity increases from improved agricultural practices.

Each value chain involves two different case studies, addressed by BIKE project and object of the present Technology Innovation System analysis, which are summarized as follows:

Value chain 1

- Castor oil for HVO: case studies in Kenya, and Italy have been considered for technology assessment. Reference countries for policy framework, actors and networks considered for the study were Italy, and Europe
- Perennial crops for bioethanol: case studies in Italy and UK have been considered. Reference countries for policy framework, actors and networks considered for the study were Italy, and Europe

Value chain 2

- Brassica oil crops for renewable diesel production: case study Uruguay have been considered. Europe was the reference area for policy framework, actors and networks assessment
- Biogas done right model (BDR) for biomethane-to-liquid fuels: case study in Italy have been considered. Reference countries for policy framework, actors and networks considered for the study were Italy, and Europe

The TIS analysis led to the development, for each case study, of:

1. A detailed matrix of the main system structural components, such as Actors, Networks and Institutions, and their corresponding activities across the value chain;
2. A set of diagnostic questions in the form of questionnaires delivered to external experts, industrial actors and project partners involved;

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3. A collection of key performance indicators, enabling the assessment of the dynamics of the technological system;
4. A spider-graph identifying the strengths and weaknesses of the system.

2 Technological Innovation System (TIS) Analysis

There is no single definition of innovation systems; however, it is clearly agreed that innovation is a collective activity placed in rapidly changing socio-economic, political and environmental contexts. Therefore, the success of an innovation system strongly depends on how it is built up and how it functions. Innovation systems may be characterized by inherent flaws, which could hamper the development and diffusion of innovations.

In this research, the analysis and the evaluation of the development of the technology innovation systems follows 3 main steps, namely:

1. **Structural analysis:**
   1.1. Identification of structural components: the structure of the innovation system, composed by actors, technology, and rules that make up the system, is identified;
   1.2. System structure determination: once defined the structure of the system, the system structure is further analyzed, guided by a literature review and diagnosis questions addressed to project partners and further research;
2. **System Functions**: the functionality of the innovation system is assessed, considering seven system functions that stem from theory and are empirically validated as indicators. Information is collected through a combination of:
   - Research activities performed within Task 3.1 and Task 3.2;
   - Information collected by other past and ongoing EC projects;
   - Diagnostic questions addressed to the project partners.
3. **Analysis and scoring of system**:
   3.1. Development of performance indicators: in order to evaluate the strengths and weaknesses of the technology innovation system, performance indicators are defined;
   3.2. System analysis: the data collected in the previous steps are evaluated for each system function, using the performance indicators determined;
   3.3. Spider-graph development: the evaluation is visualized by means of a spider-graph.

The technology innovation system in focus is the biofuels production at low-ILUC risk, which consists of two value chains, involving four different case studies. These are:

- **Value chain 1**: Cultivation in unused, abandoned or severely degraded land
  - Castor oil for HVO;
  - Perennial crops for bioethanol.
- **Value chain 2**: Productivity increases from improved agricultural practices
  - Brassica oil crops for renewable diesel;
  - Biogas done right model (BDR) for biomethane-to-liquid fuels.

Each case study may be in turn considered as technology innovation systems.

In the next sections, the aforementioned steps for the several case studies are carried out, leading to an assessment of the dynamics of the biofuels production at low-ILUC risk, identifying thus its strengths and weaknesses.

2.1 Structural Analysis

This section explains the structural components of the four case studies of the TIS in focus. The purpose of structural analysis is to identify the components of the TIS in focus, providing thus the foundation for the subsequent functional analysis. The structural components of the TIS are:

a. **Actors**, which are individuals or organizations that might have a direct contribution to a technology as a developer or adopter, or might have an indirect contribution in the form of facilitators, regulators and financers. Examples of actors are organizations responsible for education, R&D, industrial activities, and consumers;
b. **Networks**, which may relate to the linkages or associations formed between the various categories of actors [2]. Examples of networks are the linkages between organizations in research projects and advocacy coalitions;
c. **Institutions**, which are the rules, the regulations and the informal aspects (such as social norms) that shape the "rules of the game" for the TIS. A distinction can be made between formal institutions and informal institutions, being the first the rules that are codified and enforced by some authority, and the second more tacit and organically shaped by the collective interaction of actors. Examples of institutions are supportive legislation and technology standards [1];
d. **Technological factors,** which involve the techno-economic feasibility of artifacts, including costs, safety, and reliability. The technology readiness level is also measured by the number of published patents, and the existing industrial demonstrative or commercial plants currently in operation.

2.1.1 Value chains

Value chains, and thus the BIKE case studies, are normally constituted by different pathways, in which several actors, institutions and networks are involved.

As introduced, the value chains under studies are "Cultivation in unused, abandoned or severely degraded land (Value chain 1), and "Productivity increases from improved agricultural practices" (Value chain 2), which consist respectively of (i) Castor oil for HVO and (ii) Perennial crops for bioethanol, and (iii) Brassica oil crops for renewable diesel and (iv) Biogas done right model (BDR) for biomethane-to-liquid. Each case study is constituted by several pathways, shown **Figure 1**.

Once defined the Technological Innovation Systems (i.e. the four case studies) to investigate, the study could proceed with the Structural analysis, drawing up tables in which possible actors, networks and institutions for each step of the TIS(s) are identified, as well as their involvement in the different phases of the production chain, represented by a cross on the table. As case studies (i) and (iii) have relevant similarities in their constituting pathways, the same structural analysis will be carried out for both.

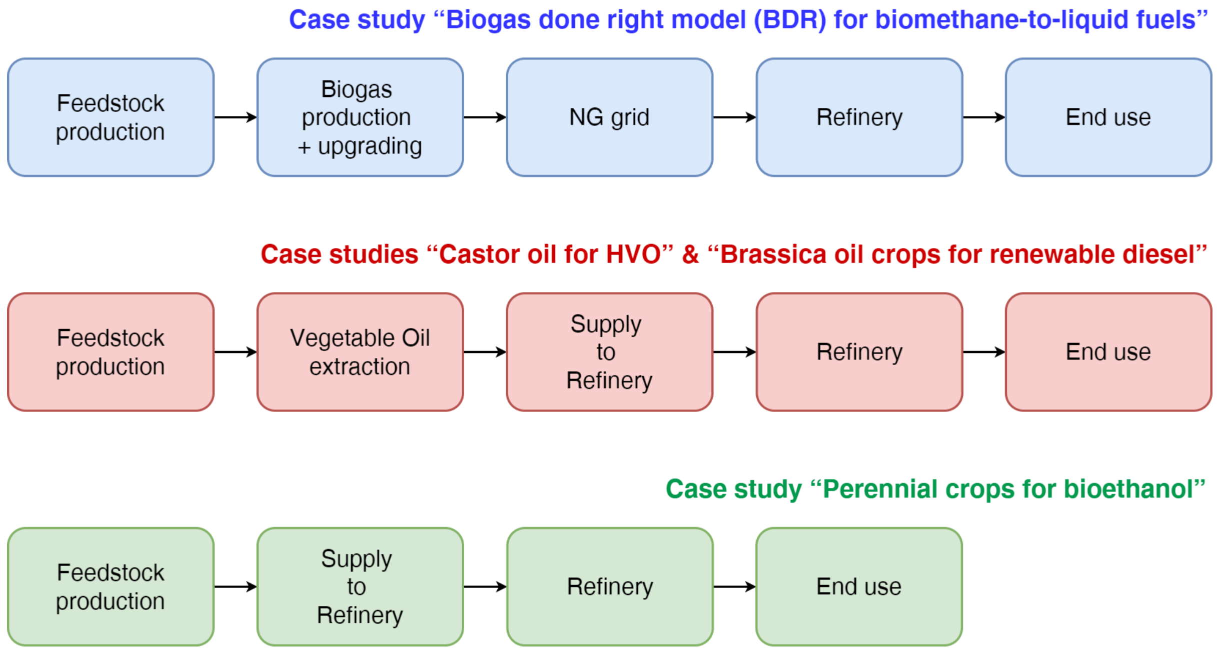

Figure 1. Value chain steps of the technological Innovation systems under investigation and related pathways for the identified case studies

2.1.2 Identification of structural components

In this section, the components of the case studies under investigation are identified.

2.1.2.1 Biogas done right model (BDR) for biomethane-to-liquid fuels

Biomethane is a gaseous fuel derived from biogenic resources treatment and subsequently conditioning to meet natural gas quality as per natural gas grid specifications [2]. To produce liquid fuels, such as FT liquids and Methanol, the biomethane extracted from the natural gas grid undergoes to further processes in the refinery sites. The pathways identified for this BIKE case study are the following:

1) Decentralized feedstock production.
2) Decentralized biogas production and upgrading to biomethane;
3) Natural gas grid;
4) Refinery (Centralized FT liquids, and MeOH production);
5) End use.

Each of these phases involve different actors, institutions, and networks. Let us analyse them.

Decentralized feedstock production

The biomethane production of the case study under investigation is based on the Biogasdoneright™ model, which is a system for on-farm biogas production. This innovative system employs sequential (year-round) cropping to produce both food and energy from agricultural biomass, primarily cellulosic materials [3], ensuring year-long covered soil and improving thus the soil quality for the main crop. **Figure 2** shows an outline of the Biogasdoneright™ system. The feedstocks in line with the BDR system could be [4]:

- Cover crops (second harvest) before or after food & feed traditional crops, thus keeping the hectares dedicated to food & feed nearly at the same level as before the biogas plant construction, and producing double crops in the period of the year when the land was set aside.
- Livestock effluents, in our case either originating at the farm or bought from neighboring farms;
- Nitrogen fixing plants, in rotation with other cereals for the market.
- Perennials in set-aside lands or lands undergoing desertification, especially where farming has been abandoned or there is no agriculture output;
- Agricultural byproducts, provided that the soil carbon fertility is at least maintained;
- Organic wastes.

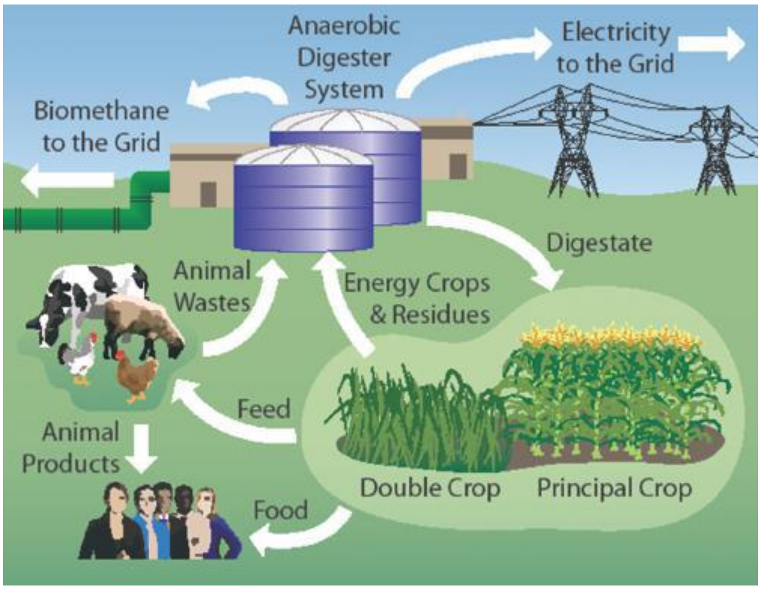

Figure 2. Outline of the Biogasdoneright™ system [4]

This step of the innovation system is considered at an advanced stage, as feedstock production, as well as related agricultural practices described above, can count on a strong structure made of actors (farmers, agricultural technology providers, research groups, etc..) institutions, and networks.

Decentralized biogas production and upgrading to biomethane

In accordance with the Biogasdoneright™ system, the process phase of decentralized biomethane production and upgrading to biomethane includes Anaerobic Digestion plants, which consist of anaerobic digestors to produce biogas, coupled with biogas upgrading plants to yield biomethane. In facts, biogas is for the mostly constituted by CH_4, water, and undesired products such as CO_2 and other contaminants such as H_2S, NH_3, N_2, and siloxane, that must be removed, or at least reduced. For this reason, national standards to ensure gas quality before injection into the natural gas grid have been formulated. The most consolidated technologies for biogas upgrading are:

a) Physical absorption, with water or organic solvents.
b) Chemical absorption, with amine or saline solutions.
c) Pressure swing adsorption (PSA);

d) Membrane separation (MB);
e) Cryogenic upgrading.

Biogas production and upgrading is a widely adopted technology for producing sustainable biofuels from agricultural residues. As described in Deliverable D3.2, the structure supporting this step of the TIS is strong, and it counts of a set of multiple actors, institutions and networks, even if only in few EU countries the incentives are sustainably high.

Natural gas grid

As introduced, the case study implies for the use of the natural gas grid to transport biomethane produced on-farm through anaerobic digestion of low-ILUC feedstocks and biogas upgrading technologies. For this reason, national standards to ensure gas quality before injection into the natural gas grid have been formulated.
The production of biomethane is strongly related to the possibility to inject it in a natural gas grid. This practice is easy in countries where natural gas grid is sufficiently developed, and where incentives justify the investment.

Refinery (FT liquids, MeOH production)

As previously mentioned, on the basis of the case study in focus, to produce liquid fuels (FT liquids and Methanol) the biomethane is extracted from the natural gas grid undergoes further processes in the refinery sites.
The routes to produce Fischer-Tropsch fuels and Methanol require syngas (a mixture of CO and H_2) as a feedstock; therefore, it is necessary to include, in the production chain, a step for reforming biomethane to syngas. The main methods that could be used to convert methane to syngas are:
a) Steam methane reforming;
b) Partial oxidation;
c) Autothermal reforming;
d) Dry methane reforming.

Syngas is then introduced in Fischer-Tropsch reactors to produce high chain hydrocarbons which are in turn further processed to be used as synthetic fuels.
Syngas serves also as a basis for methanol production through the hydrogenation of carbon oxides over a catalyst, e.g. copper oxide, zinc oxide, or chromium oxide based catalysts.
The proposed technology is well known and applicated on large scale to produce liquid from natural gas. However, the number of F.T. plants in Europe is low, due to the lack of competitiveness of this technology in the fossil fuels sector. In several places in the world, development projects are underway to produce sustainable liquid fuels from biomass.

End use

As mentioned, FT liquids are long-chain hydrocarbons which, after a further refining process, are turned into synthetic fuels, such as gasoline, diesel, kerosene and naphtha, that may be used in fuels blends or as substitutes. Instead, methanol could be used as a clean fuel, blended with other traditional fuels, or as a bulk chemical building block for the synthesis of other chemicals such as acetic acid, formaldehyde, methyl methacrylate and methyl tertiary-butyl ether (MTBE) and many others.

Table 1 shows possible Actors, Networks and Institutions for each step of the case study "Biogas done right model (BDR) for biomethane-to-liquid", and illustrates their involvement in the production chain, represented by a cross in correspondence of the specific pathway.

	Feedstock production	Biogas production and upgrading to biomethane	Natural gas grid	Refinery (FT liquids, MeOH production)	End use
Actors					
Farmers	x	x	x		
Equipment suppliers	x	x	x	x	
Plant engineering, construction, and operation companies	x	x	x	x	
Energy Supply companies	x	x	x	x	
Gas distribution companies		x	x	x	
Research Units	x	x	x	x	
Investors	x	x	x	x	
Policy makers	x	x	x	x	x
Product consumers					x
Networks					
Farmers (agricultural) associations	x				
National biogas associations	x	x	x		
National biomethane associations	x	x	x		
Environmental associations	x	x		x	
Research Associations	x	x	x	x	
Industrial Associations		x	x	x	
Local municipalities	x	x	x	x	
Public Cooperation	x	x	x	x	
Institutions					
EU Sustainability criteria	x	x	x		x
EU Renewable Energy Directive			x		x
EU Fuel Quality Directive					x
Country-Specific Agricultural policies	x				
Country-Specific Regulation on substrate usage	x				
Country-Specific Grid Access regulations (gas quality, etc.)		x	x		
Country-Specific Renewable Fuel Obligations				x	x
Incentives	x	x	x	x	x

Table 1. Structural analysis of case study "Biogas done right model (BDR) for biomethane-to-liquid fuels"

2.1.2.2 Castor oil for HVO & Brassica oil crops for renewable diesel

The second TIS identified concerns the production of Low ILUC risk renewable diesel from two types of low ILUC risk feedstock: Castor oil cultivated in abandoned or degraded lands, and Brassica oil crops cultivated as cover crop. Despite these systems differ from each other, the TIS structure has been considered to be coincident. In fact, the steps identified are the following.

Feedstock production

As investigated by WP2, low ILUC risk feedstock production represents the key of the economic sustainability of the whole value chain. In this case, Low ILUC feedstocks are represented by Brassica, cultivated as winter cover crop with leguminose, and castor oil, a non-food crop, cultivated in arid, or degraded lands. Both these practices are common in the agricultural sector, even if not exactly in Europe. In fact, large cultivation of Castor oil, or Brassica, are not yet available in Europe. Demonstrative cases have been identified by *BIKE project* in WP6.

Vegetable oil extraction process (VO production)

The vegetable oil extraction process is a widely common process, well known in the food industry for the production of vegetable oils like palm oils, sunflower oil, etc. Therefore, several actors, institutions, and network are available for this step.

Supply to refinery

Vegetable oil supply to the refineries is a key step of the whole value chain. Most of the cultivation sites, in fact, have the oil extraction unit close to the cultivation, but the refinery is usually placed far, in other regions or, sometimes, in other countries. The supply chain is thus a key aspect, often coordinated by the oil refinery company. As shown by *MUSIC project*, the efficiency of the supply chain is a key for the competitiveness of the final product.

Processing (production of HVO)

This technology is already applied at commercial scale by oil companies, as reported in Deliverable D3.1. So far, most of Vegetable oils used for HVO production have been those of food industry: palm oil, rapeseed oil, soybean oil. These feedstocks have been not included by the European Commission in the RED II.

End use

The end use of HVO is mainly as biofuels to be blended with diesel, even at high percentages, to reduce the environmental impact of the light vehicles, or to be used as precursor for jet fuels production.

Table 2 shows possible Actors, Networks and Institutions for each step of the case studies "Castor oil for HVO" and "Brassica oil crops for renewable diesel", and illustrates their involvement in the production chains, represented by a cross in correspondence of the specific pathway.

	Feedstock production	Vegetable Oil extraction	Supply to refinery	Processing(renewable diesel production)	End use
Actors					
Farmers	x				
Equipment suppliers	x	x		x	
Plant engineering, construction, and operation companies	x	x		x	
Energy Supply companies	x	x	x	x	
Energy trading units				x	x
Distribution companies			x		x
Research Units	x	x		x	
Investors	x	x		x	
Policy makers	x	x	x	x	x
Product consumers					x
Networks					
Farmers (agricultural) associations	x				
Environmental associations	x			x	x
Research Associations	x	x		x	
Industrial Associations	x	x		x	
Local municipalities	x			x	
Public Cooperation	x	x	x	x	
Institutions					
EU Sustainability criteria	x	x	x	x	x
EU Renewable Energy Directive		x			x
EU Fuel Quality Directive					x
Country-Specific Agricultural policies	x				
Country-Specific Regulation on substrate usage	x				
Country-Specific Renewable Fuel Obligations					x
Incentives	x	x	x	x	x

Table 2. Structural analysis of case studies "Castor oil for HVO" & "Brassica Oil crops for renewable diesel"

2.1.2.3 Perennial crops for bioethanol

The fourth value chain, on lignocellulosic bioethanol production from perennial crops, presents a simplified set of steps. In fact, the value chain can be distributed as follows.

Feedstock production

The production of Low ILUC woody biomass feedstock involves specific biomass perennial crops which grow in abandoned lands or, in general, in non-food dedicated areas. Lignocellulosic crops have been cultivated for more than two decades throughout Europe. They exhibit high yields, have specific traits for bioenergy and biofuel uses, and can grow in land with natural constraints that does not compete for food/feed crops. As reported by C. Panoutsou (2022), Miscanthus can be grown across all Europe and is already cultivated at commercial scale in several countries. The crop is considered beneficial for the mitigation of soil erosion and allows high level of carbon storage in soil due to high levels of plant residue from above and below ground. Switchgrass can be grown successfully across Europe in different type of soils and ecological conditions, including land with natural constraints, because of its extensive root system. It is tolerant to drought and can retain high productivity under drought conditions. Giant reed is a common weed in the Mediterranean, and it is known to be invasive and out-compete other crops. It is drought tolerant and can also grow in saline, poor texture soil with steep slopes, as well as in contaminated lands for phytoremediation.

Supply to refinery

Biomass supply, like for value chains on HVO production, is a key driver of the sustainability and economic reliability of the whole value chain. Usually, the woody biomass transportation changes depending on the characteristics of the biomass. In case of lumps, it is cut, chipped and transported by truck. In case of stalks, residues, and straw, it is usually compressed, or chipped, before being transported to the refinery.

Processing (bioethanol production)

The process of producing bioethanol from lignocellulosic biomass is complex and includes specific treatment steps: pre-treatment, enzymatic hydrolysis, and fermentation. There are different pre-treatment methods available to convert plant polysaccharides into fermentable sugars. In order to obtain a successful and efficient pre-treatment method, one must minimize the inhibitory compounds for enzymatic hydrolysis and fermentation, decrease the loading capacity of the enzyme in order to obtain efficient hydrolysis, avoid loss of sugar in pre-treatment fractions, obtain lignin and other compounds' recovery for ongoing conversion, and ensure the efficient use of energy [6]. There are different pre-treatment methods used for the disruption of plant cell walls, such as physical, chemical, physicochemical, and biological pre-treatment methods. Physical pre-treatment methods include ultrasound and milling, which reduces the particle size, crystallinity index, and polymerization degree. Chemical pre-treatment methods involve acid pre-treatments, which allow hydrolysis and the removal of hemicelluloses with the use of diluted acids. Alkaline pre-treatments, with the use of alkaline solutions enable a high digestibility of cellulose while removing lignin or breaking bonds in the lignin carbohydrate complex. *Organosolv* pre-treatment processes increase the volume of substrates' pores and surface area. Enzymatic hydrolysis presents an important process in the conversion of cellulose in pre-treated biomass. The conversion of cellulose to glucose is performed by cellulase enzymes under mild conditions, such as temperature from 40 to 50 °C and pH around 4.5 and 5. An important role in the efficiency of hydrolysis presents the pre-treatment process of lignocellulosic biomass. Such pre-treatment process includes lignin removal, hemicellulose solubility process, duration of hydrolysis, and enzyme loading. Finally, the fermentation process can be achieved over continuous, batch, and fed-batch fermentation, while fed-batch in stirred tank is the primary choice in industrial fermentations because of its ability to provide optimal conditions. Glucose fermentation with the use of robust industrial host strains can elevate yields of ethanol due to its high specific ethanol productivity.

End use

Bioethanol can be used for multiple applications. In particular, light vehicles transportation biofuel and precursor of ethylene are considered the most promising market sectors.

Table 3 shows possible Actors, Networks and Institutions for each step of the case study "Perennial crops for bioethanol", and illustrates their involvement in the production chains, represented by a cross in correspondence of the specific pathway.

	Feedstock production	Supply to refinery	Refinery (Ethanol production)	End use
Actors				
Farmers	x			
Equipment suppliers	x		x	
Plant engineering, construction, and operation companies	x		x	
Energy Supply companies	x	x	x	
Energy trading units			x	x
Distribution companies		x		x
Research Units	x		x	
Investors	x		x	
Policy makers	x	x	x	x
Product consumers				x
Networks				
Farmers (agricultural) associations	x			
Environmental associations	x		x	x
Research Associations	x		x	
Industrial Associations	x	x	x	
Local municipalities	x		x	
Public Cooperation	x	x	x	
Institutions				
EU Sustainability criteria	x	x	x	x
EU Renewable Energy Directive		x		x
EU Fuel Quality Directive				x
Country-Specific Agricultural policies	x			
Country-Specific Regulation on substrate usage	x			
Country-Specific Renewable Fuel Obligations				x
Incentives	x	x	x	x

Table 3. Structural analysis of case study "Perennial crops for bioethanol"

2.1.3 Determining the system structure and phase of development

In order to complete the assessment of the structure of the case studies under investigation, the identification of actors, institutions and networks has been enriched with a further system analysis, for each case study. To this aim, a literature review has been performed, and project partners have been requested to answer to some diagnosis questions. As a last step of defining the system structure, the phase of development of the technology is determined. In order to determine in which phase of development the technology resides, diagnostic questions can be asked. Questions are reported below:

a) Pre-development phase: Is there a working prototype?
b) Development phase: Is there commercial application?
c) Take-off phase: Is there a fast market growth?
d) Acceleration phase: Is there market saturation?

If the answer is yes, then the technology is in the next phase of development. The result of this short questionnaire is used to place the technology in the phase of development trajectory, visible in figure below.

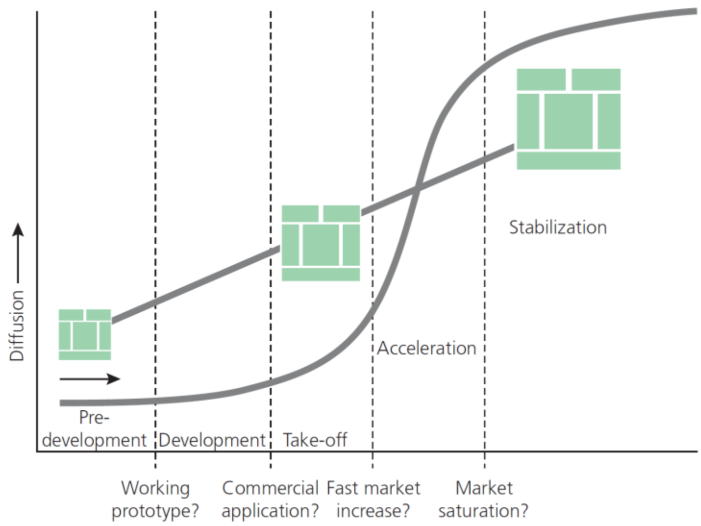

Figure 3. TIS Phase of development trajectory

The system structure and phase of development assessment of each value chain is reported below.

2.1.3.1 Biogas done right model (BDR) for biomethane-to-liquid fuels

The information collected in the current phase for the case study “Biogas done right model (BDR) for biomethane-to-liquid fuels” could be considered satisfying regarding the upstream phases of the value chain; however, the level of detail reached for the downstream pathways (refinery) is lower with regards to the others. The lack of information is considered itself an indicator of the readiness level and the state of development of the identified TIS. Moreover, as the project partner dealing with this case study, namely CIB (Consorzio Italiano Biogas) mainly operates in Italy, the information gathered concerning Italy is richer than that collected for the rest Europe.

Regarding the **Actors** that have been identified in the "Biogas done right model for biomethane-to-liquid fuels" case study.
It is difficult to quantify the numbers of **farmers** that are currently producing low-ILUC feedstocks for biomethane production in Europe; however, according to the project partner CIB an important number of farmers with biogas plants are using double crops according to the BDR model, thus respecting the required criteria, and many farmers have already decided to invest in the model and are applying it successfully. The number of **biomethane plants** currently (2021) operating **in Italy** is 28. At EU level, as reported in D3.1, biomethane plants along the last 10 years have been raising at fast rate. The strong increase of biomethane plants installed in Europe and, by consequence, of biomethane volumes production is an evidence of the number of farmers approaching this practice.
Regarding other actors in the value chains, technology providers are widely available both at Italian and EU level, thanks to the profitability shown by the biogas sector in the last year. A reduced number of technology providers is identified for the downstream part of the value chain: the biomethane upgrading into bioliquids. As mentioned in the introduction, the scalability of Fischer-Tropsch is proven at commercial level for converting coal (Sasol plant in South Africa, 170 000 bpd[1] combined capacity) and natural gas (Pearl GTL in Qatar, 140 000 bpd). There are a few smaller commercial installations for natural gas-based FTS. Current and announced commercial SAF oriented FT installations indicate nearly 300 million litres of FT liquid production by 2025. In the beginning of 2021, Fulcrum bioenergy and Essar Oil UK announced *Fulcrum NorthPoint project* which aims for annual SAF production of 100 million litres at Essar Oil site in Stanlow, UK. *Fulcrum NorthPoint* will see estimated budget £600 million with planned production start-up date in 2025 (Source: ETIP Bioenergy 2021).

With regards to the **Networks** of this case study, in line with Italian Biogas Consortium (CIB), there are several agricultural associations in Italy, as well as umbrella organizations promoting biogas and biomethane. However, there is no evidence that environmental associations and research associations currently involved in the specific case study of Biogas Done Right model exist. At the same time, literature shows how EU organizations on biogas, biomethane, sustainable farming are approaching the sustainable practices for biomethane production at farm level, supporting the development of biomethane production plants respecting the Low ILUC risk criteria.

For what matters the **Institutions** involved, the sustainability criteria related to the case study are those set in the Renewable Energy Directive II, in which the concept of low-ILUC has been defined.
According to the project partner CIB, there are no country-specific agricultural policies and neither country-specific regulations on substrate usage for the production of low-ILUC feedstocks.
Regarding the natural gas grid access regulations (gas quality, etc.), Italy is a driving country at EU level. In Italy, the UNI/TR 11537 regulation is the one to be respected for the injection of biomethane into the national gas grid. Moreover, with the aim of supporting the transition to a to low-carbon mobility, the Italian Government issued the *"Decree of the Ministry of Economic Development of March 2nd 2018"* (updated April 2022), introducing incentives for biomethane injected into the natural gas grid and for advanced biofuels to be used in the transport sector.

[1] Bpd = Barrels per day

However, there is no incentive decree in all European nations; to have an idea of the scenario, we can consider that there are biomethane plants in 21 European countries.

At EU level, as shown in the Deliverable D3.1, the European Biogas Association promotes the development of biomethane production plants as advanced transportation biofuel. Farmers approaching the anaerobic digestion process are a growing number in Europe and, despite not all AD plants are currently applicating the BDR model, the number of potential actors can be considered high.

Regarding the technology, 10144 patents related to "anaerobic digestion for biogas production", have been identified on "Worldwide Espacenet"[2] patents database. Of these, 482 patents related to "anaerobic digestion for biomethane production". The research on patents related to Fischer-Tropsch process produced 50573 patents, while 175673 patents resulted by searching "methanol production from methane". Despite their generic value, these numbers confirm the strength and well development level of the technology. In order to quantify the phase of development, the above-reported questions have been answered as follows:

a) Is there a working prototype? Yes;
b) Is there commercial application? Yes;
c) Is there a fast market growth? The market growth, as reported also in D3.1, is fast for the biomethane production sector. On the contrary, despite the high technology readiness level, a reduced performance is identified for the "methane to liquid" step;
d) Acceleration phase: Is there market saturation? No.

Based on the answers above, the phase of development is considered at the take-off for BIKE case study. The result is reported graphically in Figure 4.

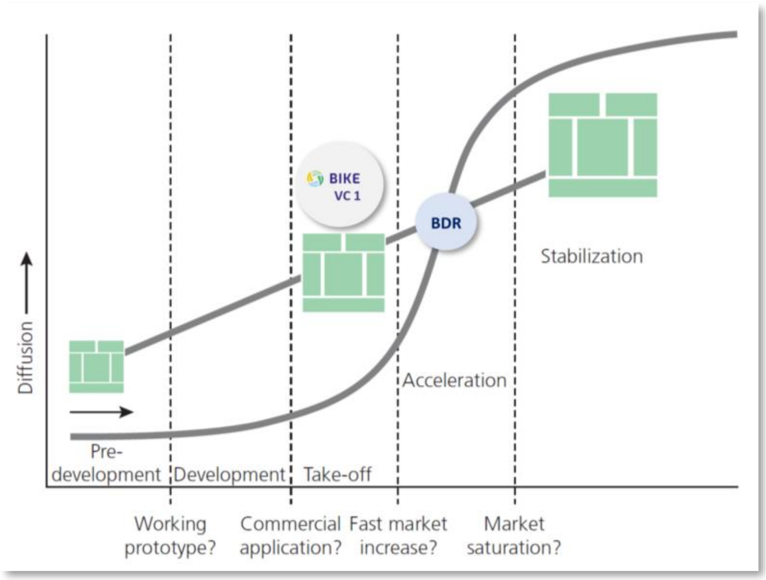

Figure 4. Phase of development of BIKE case study on BDR for biomethane-to-liquid fuels

[2] https://worldwide.espacenet.com/

2.1.3.2 Castor oil for HVO & Brassica oil crops for renewable diesel

For the structural analysis, the two case studies of "Castor oil for HVO" and "Brassica oil crops for renewable diesel" have been assessed together. In fact, despite the case studies are based on two different Low ILUC risk feedstock production systems (Castor: cultivation on degraded lands; Brassica: additionality measure with cover cropping) the structure and the steps of the two value chains is very similar. In particular, all the value chain actors are coincident: feedstock production, vegetable oil extraction, supply to refineries, HVO synthesis, and distribution to end users. The difference stays mainly in the agricultural practice adopted for the production of feedstock, but the identified number of potential actors (i.e. farmers) involved in this first step is considered equal for the two cases. When technical, regulatory, and more specific indicators will be assessed in the report, the two case studies will be analysed separately.

For what matters case study "Castor oil for HVO", the amount of information collected regarding actors, networks and institutions can be considered fulfilling. A set of diagnosis questions have been addressed to project partners ENI (on Castor oil), UPM (on Brassica oil) and EXERGIA (on Policy measures).

Let us focus on the **Actors** involved in the case study.

In Italy, ENI is working on the construction of a supply chain of **farmers** in the southern central regions and in 2021 has formed a Joint Venture with *Bonifiche Ferraresi*, a leading agricultural group in Italy, with the aim of developing research activities and to provide agronomic know-how on agri-feedstock cultivation (e.g. through a field trial on oil crops in Sardinia started in April 2022). The target is the cultivation of low-ILUC feedstock, mainly cover crops, in the degraded areas of Sardinia, Puglia, Basilicata and Sicily.

In Kenya, ENI has already involved about 25000 **farmers** grouped in 20 cooperatives that will begin to deliver Castor from autumn 2023.

In Italy the farmers have all the necessary **equipment** and there is already a network of plants for oil extraction system (both mechanical and chemical) and cake valorisation.

In Kenya the current model is mainly based on family farming also due to the lack of the equipment/suppliers in the county. For all the phases involved in the case study, ENI will make sure that all the equipment will be available (e.g. tractors for soil preparation, seeds for cultivation, equipment for shelling after harvest).

In general, castor oil extraction process is more common in non-EU countries, like Asia (India) and Africa. At EU level, the sector has a now a niche dimension. About Brassica, the cultivation of Brassica Carinata and other species of this oil crop have been widely demonstrated during different farming experiences in EU southern countries, like Italy, Greece, etc. Rapeseed (Brassica napus) is already used to produce biodiesel, and there is also interest from the chemical industry for the use of rapeseed HEARto produce 'green' chemicals. Rapeseed is also considered an effective break crop in cereal rotation because it results in higher-yielding cereal crops and weed control. Like for Castor oil, the cultivation of Brassica Carinata as cover crop in Europe is not yet performed at large scale. However, the number of farmers which could be potentially involved in the Castor oil, or Brassica oil production addressed to Low-ILUC risk extraction is considered high. In general, the number of farmers is considered an opportunity, and not a barrier to unlock the market potential of this value chain.

Regarding **Vegetable Oil extraction plants** EU, every European country already has a stable infrastructure. Facilities for processing Castor oil are not yet available in Europe since it must be segregated from food oils for the health & safety issue.

About technology providers of **HVO plants**, as we have seen in DP3.1, in Italy ENI owns two operational plants, one in Venice and one Gela, both using the proprietary Ecofining™ technology. More in general, HVO production plants are operating in different EU countries, even if they process different types of vegetable oils, mainly UCO[3] and palm oil. Despite the slight difference of Castor oil, and Brassica Carinata oil from UCO and palm oil, technology providers are now sufficiently available to ensure the development of the proposed TIS.

Over the issue of **energy supply**, in Italy the availability of energy is not a constraint, same for EU member states. Therefore, no issue about energy network and distribution actors are seen in Europe. On the contrary, in other countries with less developed infrastructure, like Enya, Congo, south of America, the use of decentralized energy sources, integrated with renewable energy is an opportunity. The ENI Agrihub is connected to the electricity grid (80% renewable energy) and it is to date equipped with an endothermic diesel engine for back up.

Concerning the **distribution companies** involved in the case study on low ILUC HVO production, ENI, in addition to producing, also deals with distributing HVO. The same is for UPM, as well as for most of refinery companies.

Regarding the **Research Units** involved in the case study, in Italy ENI collaborates with *Bonifiche Ferraresi* and its research units on the case study. In addition, ENI is a founding member of the "spoke" 1, 2, 7 and 8 of Agritech (*Centro Nazionale di Ricerca per le Tecnologie).* The above "spoke" – 1 "Plant and animal genetic resources and adaptation to climatic changes", 2 "Crop Health: a multidisciplinary system approach to reduce the use of agrochemicals", 7 "Integrated models for the development of marginal areas to promote multifunctional production systems enhancing agroecological and socio-economic sustainability" and 8 "New models of circular economy in agriculture through waste valorization and recycling" – are coordinated, respectively, by the *CNR, Università degli Studi di Napoli Federico II, Università degli Studi di Bari Aldo Moro* and *Università degli Studi di Milano*. ENI collaborates with the Universities in the development of the different initiatives.

In Kenya ENI collaborates with the Kenyan Agricultural and Livestock Research Organization (KALRO) with the scientific support of the University of Bologna.

Moreover, ENI is developing initiatives and **investing** in the mentioned case studies, and has launched sustainable mobility program, also leveraging on the distribution and production of low ILUC risk biofuels. In general, thanks to the engagement of industrial actors and the strong interest in this value chain, a growing number of actors are involved in the value chain of Low ILUC risk castor oil production for HVO, pushing its market development.

Let us examine now the **Networks** involved in this case study.

In Italy, ENI has signed a national agreement with the **agricultural association** *Coldiretti* and also a regional agreement with *Coldiretti Basilicata*. Moreover, ENI has launched discussion tables with the main environmental associations in Italy and in Europe. UPM is involved in a wide range of EU and international networks and technology platforms promoting low ILUC risks biofuels development and standardization. Some examples of European agricultural associations involved in Castor oil and Brassica Carinata case study are:

1. **Committee of Professional Agricultural Organization (COPA)[4].** It represents the European farmers and agri-cooperatives. Their objectives are:

[3] UCO = Used Cooking Oil
[4] http://www.copa-cogeca.be/

- To promote the best interests of the sector among EU institutions and other relevant stakeholders;
- To develop effective strategic policies and initiatives to raise awareness for the multifunctional role of farms and promote a decent income for farmers;
- To act as the central network for farming issues for its members and provides a platform for exchanges to develop solutions to any technical or trade barriers within the EU and beyond;
- To communicate with a view to maintaining a strong presence within the EU public discourse by explaining its positions;
- To participate in every relevant international platform in order to promote and disseminate the positions of European farmers;

2. **European Landowners Organization (ELO)**[5]**.** It represents landowners in EU countries. Their objectives are:
   - To promote a sustainable and prosperous countryside and to increasing awareness relating to environmental and agricultural issues;
   - To engage various stakeholders;
   - To develop policy recommendations and programmes of action;
   - To organise interdisciplinary meetings gathering together key actors from the rural sector and policy makers at the local, regional, national and European level.
3. **European Forest Institute**[6]. It represents 30 European states and 130 member organizations from 40 countries. Their objectives are:
   - To provide support and promote the dissemination of scientifically sound policy-relevant information on forests and forestry.
   - To provide interdisciplinary and cross-sector research on forest resources, products and services on a pan-European level.

Regarding **environmental associations**, currently none is involved in any of BIKE cases implementation and analysis.
On the other hand, there are many **research centres** involved in this case study and working in EU research projects like BIKE, Music, BIOMAP, as well as national research activities in different EU countries.
In reference to the **Institutions** taking part of this case study, and more specifically to the related **EU Sustainability criteria**, the Commission, in its delegated act, has laid down criteria to determine high ILUC risk feedstocks. ISCC is working to develop a low ILUC certification scheme. For this purpose, in June three pilot audits will be carried out in three locations at ENI Kenya. More in detail, the case study of castor oil/HVO matches the additionality measure for cultivation in unused, abandoned or severely degraded land. Moreover:

- Any biomass intended for use as a REDII-compliant biofuel feedstock must satisfy the sustainability criteria in the REDII[7] Article 29 Paragraphs 3-6. These proscribe, for instance, conversion of peatland to agricultural production.

[5] https://www.europeanlandowners.org/
[6] https://efi.int/
[7] DIRECTIVE (EU) 2018/2001.

- Any biofuel seeking REDII compliance must satisfy the sustainability criteria in the REDII Article 29 Paragraph 10, which places minimum limits on the greenhouse gas savings arising from displacing conventional fossil fuel.
- Any country wishing to produce REDII-compliant biofuels must satisfy the sustainability criteria in the REDII Article 29 Paragraph 7, which requires that origin countries are party to the Paris climate agreement.

For what matters the **Country-Specific policies and regulations** for the production of low-ILUC feedstocks, within the countries (GR, IT, KE, UR) where case studies of Castor Oil and Brassica are implemented, it has not been identified any Agricultural policy nor regulations on substrate usage for the production of low-ILUC feedstocks.
Regarding the regulations for the raw/product distribution sector, in order to contribute to renewable energy targets, biofuels and their feedstocks must submit to logistical monitoring and reporting regulations set out in the REDII. These include:

- Article 30 Paragraphs 1-2 on mass balance accounting and consignment mixing;
- Article 30 Paragraph 3 on accurate declaration of greenhouse gas savings;
- Article 30 Paragraph 7 on bad-faith modification of feedstocks;
- Article 30 Paragraph 9 on the use of voluntary sustainability schemes to substitute some reporting requirements;
- Article 28 Paragraph 2 on fuel suppliers' reporting obligations for the purpose of minimising double-counting risks.

Economic operators dealing with low ILUC-risk biofuels must furthermore satisfy specific criteria set out in the Delegated Regulation on ILUC risk[8], including:

- Article 6 Paragraph 1 on reporting on satisfaction low ILUC-risk criteria, and auditing of said reports.

The obligations to be respected in Europe in the matter of renewable fuels are:

- The Fuel Quality Directive (2009/30/EC);
- Directive (EU) 2019/1161 on the promotion of clean and energy-efficient road transport vehicles;
- Regulation (EU) 2019/631 setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles.

Turning to **incentives**, at the Member State level, there are a variety of schemes for promoting the production and use of biofuels, including HVO. These fall into the following general overlapping categories[9]:

- Quotas, where a stated share of transport fuel (by volume or by energy) is required to come from renewable sources. Quotas are in effect in 23 EU countries[10] [11]; since

[8] COMMISSION DELEGATED REGULATION (EU) 2019/807.
[9] Following Banja et al 2019, https://doi.org/10.1016/j.enpol.2019.04.038.
[10] Belgium, Bulgaria, Czech Republic, Denmark, Ireland, Greece, Spain, France, Italy, Latvia, Lithuania, Luxembourg, Croatia, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland.
[11] Germany had a biofuel quota but replaced it in 2015 with a greenhouse gas reduction quota, which only indirectly supports usage of biofuels.

quotas are relevant at the national level, more specific mechanisms are applied by governments to directly incentivise the private sector to produce biofuel[12].

- Tax credits, where partial tax or fuel duty exemptions are applied to renewable fuels. Such initiatives are active in 15 EU countries[13].
- Subsidies, where direct payments are available to biofuel suppliers, are available in six countries[14].

Incentives may be augmented in specific situations: the REDII establishes a mechanism to "double count" advanced biofuels made from feedstocks listed in Annex IX of the REDII[15].
In Italy, in Article 17 of "*Testo del decreto-legge 1° marzo 2022, n. 17 – Misure urgenti per il contenimento dei costi dell'energia elettrica e del gas naturale, per lo sviluppo delle energie rinnovabili e per il rilancio delle politiche industriali*" is reported:

- from 2023, the share of sustainable biofuels used in purity is at least 200 thousand tonnes, which increases by 50 thousand tonnes per year in the following three years;
- In order to support the promotion of biofuels used in purity, including through the conversion of traditional refineries within *sites od national interest (SIN)* for the production of biofuels to be used in purity, is established the fund called "*Fondo per la decarbonizzazione e per la riconversione verde delle raffinerie ricadenti nei SIN*"

Regarding the technology, 48127 patents related to "hydrogenation of vegetable oil", have been identified on worldwide espacenet patents database. Of these, 971 patents related to "hydrogenation of vegetable oil for green diesel" have been found. The research on patents related to castor oil hydrogenation process produced 23207 patents. Despite their generic value, these numbers confirm, also in this specific case, the strength and well development level of the technology. To quantify the phase of development, the above-reported questions have been answered as follows:

a) Is there a working prototype? Yes;
b) Is there commercial application? Yes;
c) Is there a fast market growth? No;
d) Acceleration phase: Is there market saturation? No.

Based on the answers above, the phase of development is considered at the take-off for BIKE case study. The result is reported graphically in Figure 5.

[12] For example, the Netherlands awards renewable energy credits to suppliers of biofuels, which can be traded with fossil fuel suppliers to meet legislated renewable energy obligations for fuel suppliers.
[13] Belgium, Czech Republic, Denmark, Greece, Latvia, Lithuania, Hungary, the Netherlands, Austria, Portugal, Slovenia, Slovakia, Finland, France, Sweden.
[14] Estonia, Greece, Lithuania, Hungary, Austria and Slovenia.
[15] There is some discretion in whether and how to apply this mechanism. Several member states have developed their own lists of feedstocks eligible for double counting.

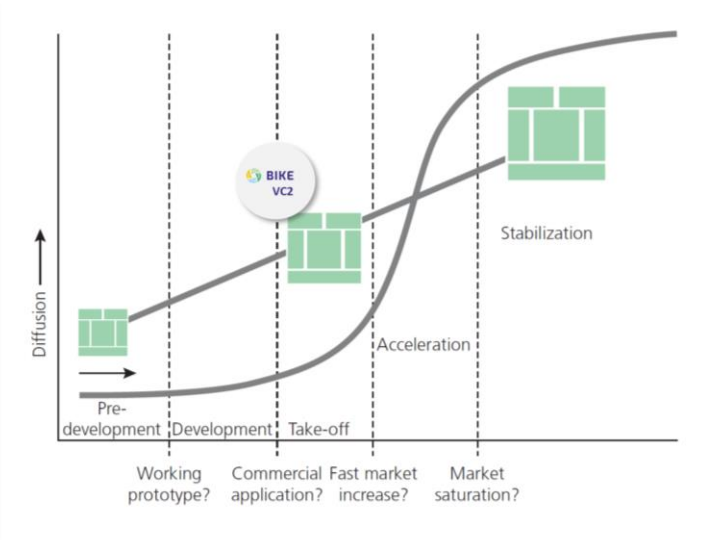

Figure 5. Phase of development of BIKE case study on Castor oil and Brassica oil crops cultivation for HVO

2.1.3.3 Perennial crops for bioethanol

The system structure of case study "Perennial crops for bioethanol" has been determined thanks to the experience of project partner RE-CORD, leader of the case study, and based on the information found in literature.
Let us focus on the **Actors** involved in the different steps of lignocellulosic ethanol value chain.
As regards the **farmers**, it is important to mention that most of lignocellulosic biomass produced in low-ILUC conditions is not used for bioethanol production. However, many case studies on perennial crops cultivation have been identified in all EU member states. In particular, the recently published paper by C. Panoutsou et al. (2021) [7], Miscanthus can be grown across all Europe and is already cultivated at commercial scale in several countries. The crop is considered beneficial for the mitigation of soil erosion and allows high level of carbon storage in soil due to high levels of plant residue from above and below ground. Switchgrass can be grown successfully across Europe in different type of soils and ecological conditions, including land with natural constraints, because of its extensive root system [8,9]. It is tolerant to drought and can retain high productivity under drought conditions. Giant reed is a common weed in the Mediterranean, and it is known to be invasive and out-compete other crops. It is drought tolerant and can also grow in saline, poor texture soil with steep slopes, as well as in contaminated lands for phytoremediation [8,9,10]. Therefore, it can be said that, despite lignocellulosic ethanol is not considered a primary end use for perennial lignocellulosic biomass, farmers involved in this activity are many, and could dedicate production to ethanol industries if economic conditions would become favourable. The **equipment suppliers** involved in the value chain are common of distillation industries.
For what matters the ethanol production plants, as we have seen in BIKE WP3/D3.1, in Europe there are 4 demo plants, producing about 40000 t/y produced in total. As an example, we can mention *Versalis Crescentino* plant, with a capacity of 200000 t/y of lignocellulosic biomass. The enzymes and the equipment for the hydrolysis process, as well as the biomass fractionation pre-treatment technologies required for the bioethanol production process are commercialized by specialized providers commonly operating in the chemical, and pharmaceutical sectors.

Energy supply companies appear to be enough, as well as **distribution companies**, being them same as gasoline companies. Also private traders are available[16].
The **Research Units** involved in the several phases of the case study are biologists, agronomists, chemical engineers, chemists. Private companies are interested to **invest** in this case study, due to Emission trading system and to the supporting measures included in the EU RED II, while the main **product consumers** of bioethanol we find Gasoline companies (to produce E5 fuels, etc.).
End users of lignocellulosic bioethanol are mainly those of first-generation ethanol: light vehicles fuel companies, and ethylene producers. However, due to the reduced percentage of bioethanol admitted in modern internal combustion engines, and to the competitiveness of first-generation ethanol produced from sugar crops, the end users of lignocellulosic ethanol are now lower than those identified for other case studies. However, the number of end users is limited not for a structural point of view, but for economic reasons.
Let's turn now to the **Networks** taking part of the "Perennial crops for bioethanol" case study.
We can mention the agricultural associations Copa Cogeca[17] and EU forests owners[18]. Additionally, umbrella organization and EU technology platforms focusing on sustainable bioethanol production are well known, and actively operating. Among them, it worth to mention EPure[19], also reported in BIKE WP3/D3.1., EUBIA, ETIP biofuels, Bioenergy Europe.
About the **environmental associations** in EU involved in the case study, European Environmental Bureau (EEB) umbrella association of EU national environmental associations can be mentioned.
In general, it can be stated that actors involved in this case study are available, both from knowledge, research, equipment and technology point of view. Large scale feedstock production is still not in place, mainly due to the competitiveness of other sectors based on biomass end use.

Let us consider now the **Institutions**.
The EU Sustainability criteria related to the case study under investigation are reported in BIKE WP1, i.e. Delegated regulation, Low ILUC risk biofuels, REDII 2018, etc.
Regarding the **Country-Specific Agricultural policies** for the production of the low-ILUC feedstocks involved in this case study, we can report National Renewable Energy Plans, which includes specific policies for advanced biofuels. A significant amount of information can be found in BIKE WP5, also dealing with Country-Specific Regulation on substrate usage and regulations related to raw/distribution in EU.
About the **Renewable Fuel Obligations in EU**, we recall that the Renewable Energy Directive (RED) mandates that 20% of all energy usage in the EU, including at least 10% of all energy in road transport fuels, be produced from renewable sources by 2020.
As regards **incentives**, there are no incentives specifically for the production of bioethanol in EU. More in detail, the multiple counting mechanism is in place in 21 Member States and the UK. The mechanism is not in place in Bulgaria, Germany, Greece, Lithuania and Sweden. The mechanism is partially implemented in Slovakia only for the purposes of EU and national reporting.

- Tax incentives for biofuels/blends: o None: Belgium, Bulgaria, Cyprus, Estonia, Germany, Greece, Hungary, Italy, Malta, The Netherlands, Poland, Romania, Spain, United Kingdom;
- Lower tax for low biofuels blends: Austria, Denmark, France, Slovakia, Sweden;

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[16] https://ekofuel.org/trade-sales
[17] https://www.copa-cogeca.eu/
[18] https://www.cepf-eu.org/
[19] https://www.epure.org/

- Lower tax for high biofuels blends: Czechia, Denmark, France, Latvia, Lithuania, Sweden;
- Taxation based on the energy/CO_2 content: Finland;
- No excise duty/exempted from certain taxes (components): Croatia, Ireland, Latvia, Luxembourg, Portugal, Slovenia.

Incentives are provided on different biorefinery processes, including clean energy production, CO2 certificates, etc. However, despite institutions are approaching and working on this case study, a lack of a clear vision by EU and national institutions concerning lignocellulosic bioethanol contribution to the transport fuel energy mix is considered a weakness in the structure supporting the development of this case study.
Regarding the technology, 11077 patents related to “lignocellulosic ethanol”, have been identified on worldwide espacenet patents database. Moreover, 17616 patents related to “biomass enzymatic hydrolysis” have been found. The research on patents related to “biomass fractionation process” produced 8725 patents. Despite their generic value, these numbers are lower than those identified for the other value chains. Despite the lignocellulosic ethanol process has been widely studied and optimized, producing a relevant number of patents, the development level of the technology is still between demonstration and commercial stage. To quantify the phase of development, the above-reported questions have been answered as follows:

a) Is there a working prototype? Yes;
b) Is there commercial application? Only few cases available;
c) Is there a fast market growth? No;
d) Acceleration phase: Is there market saturation? No.

Based on the answers above, the phase of development is considered at the take-off for BIKE case study. The result is reported graphically in **Figure 6**.

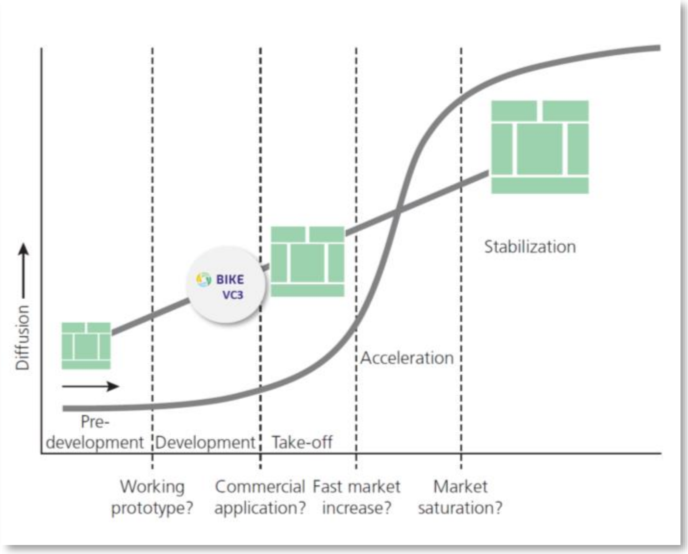

Figure 6. Phase of development of BIKE case study on Perennial crops for lignocellulosic ethanol production.

2.2 System Functions

This section addresses the system functions of the TIS (technology system innovation) in focus, namely the four case studies for biofuels production at low-ILUC risk. The system functions are characterized by a series of diagnosis questions, that enable the establishment of a functional pattern to identify the strengths and the limitations of the system in focus. These functions can be described as:

1. F1 – Entrepreneurial Experimentation and Production;
2. F2 – Knowledge Development.
3. F3 – Knowledge Exchange.
4. F4 – Guidance of the Search.
5. F5 – Market Formation.
6. F6 – Resource Mobilization.
7. F7 – Counteract resistance to change/legitimacy creation.

In the next paragraphs the identified set of system functions is further elaborated. The diagnosis questions addressed to the project partners are the same for all the case studies considered.

2.2.1 F1 – Entrepreneurial Experimentation and production

This function addresses the supporting conditions such as policies, standards and regulations, which are formed as a result of experimental activities and trials conducted by the actors involved in the system. The weaknesses of the system could be evaluated through the following questions:

a. Are the actors identified in the structural analysis relevant and sufficient?
b. Is the trend of growth of the actors in the value chain inclining or levelling?
c. Is the lack of actors in certain category forming a barrier for the development of the biofuels production chain?
d. Do the industrial actors focus sufficiently on large sale production?

e. Do the industrial actors innovate sufficiently?

2.2.2 F2 – Knowledge Development

The scope of this function is to evaluate the available knowledge base of the TIS, its accessibility and its flow to the respective actors. Knowledge development can be distinguished as:

- Scientific and technological knowledge;
- Production and operating knowledge;
- Operating market conditions knowledge;
- Application-specific knowledge.

This system function can be assessed through the following questions:

a. Is the amount/quality of knowledge development sufficient for the development of the innovation system?
b. Does the type of knowledge developed fit with the knowledge needs within the innovation system?
c. Does the quality and/or quantity of knowledge development form a barrier for the TIS development?
d. Are enough pilot trials conducted?

2.2.3 F3 – Knowledge exchange

This system function is aimed to evaluate the type and the amount of networks, and can be assessed through questions such as:

a. How many or how frequently are conferences and workshops being conducted?
b. What is the participation level of the actors within the conferences and workshops?
c. Is there enough knowledge exchange between science and industry?
d. Is there enough knowledge exchange between users and industry?
e. Is there sufficient knowledge exchange across different countries?
f. Is knowledge exchange forming a barrier for the IS to move to the next phase?

2.2.4 F4 – Guidance of the Search

This function relates the motivation of the actors to take part to the growth and propagation of the TIS, considering all the mechanisms involved. The following diagnostic questions could be submitted:

a. Is there a clear vision on how the industry and market should proceed in terms of growth and technological design?
b. What are the expectations regarding the technological field?
c. Are the visions and expectations of actors involved sufficiently aligned to reduce uncertainties?
d. Does this (lack of) shared vision block the development of the TIS?
e. Is the substrate potential of biofuels production studied within the country context?

f. Is such a study available to the actors in the value chain?
g. Do national targets for biofuels production exist?
h. Is there a national target or recommendation to substitute a percentage of fossil fuels with biofuels?
i. What are the governmental policies in support of low ILUC risk biofuels?
j. Are there any national targets for vehicle fuel substitution with renewable fuels?
k. Are there any restrictions on usage of substrate?

2.2.5 F5 – Market Formation

This system function analyses the formation of a marked aroused from the TIS. To this end, it is important to identify the possible demand from the perspective of the end user, and the possible existence of a present or competitive market.

In order to evaluate which end utilization is being promoted or which end utilization has a larger potential for utilizing the biofuels produced, the following questions can be submitted:
a. Is the current and expected future market size sufficient?
b. Does the market size make a barrier for the development of the TIS in focus?
c. Does a niche market application for biofuels exist, or is it being promoted?
d. Are there any finance incentives for biofuels production?
e. Are there any finance incentives for biofuels utilization?
f. How extensive is the biofuels filling station infrastructure?
g. Do vehicles running with biofuels form a growing segment or niche segment?

2.2.6 F6 – Resource Mobilization

The development of the TIS in focus leads to the mobilization of a set of resources, such as human resources (skilled labor), financial resources (investments, venue capital, subsidies, etc.), and physical resources (infrastructure, material, etc.). To this end, the following diagnostic questions could be submitted:
a. Are there sufficient skilled human resources?
b. Are there sufficient financial resources?
c. What is the status of Government funding projects in this sector?
d. Are there any tax benefits or investment subsidies on vehicles running with biofuels?
e. What is the status of access to financing options?
f. Is the physical infrastructure developed well enough to support the diffusion of technology?
g. Are there expected physical resource constraints that may hamper technology diffusion?

2.2.7 F7 – Counteract resistance to change/legitimacy creation

This function assesses the perception of the actors involvement along the value chain. Legitimacy could be either direct (i.e. with regards to compliance with established institutions) or indirect (i.e. with regards to end user acceptance of the TIS). As regards the biofuels production at low ILUC risk, the use of biomass to produce energy has definitively high environmental benefits, but nevertheless there could be resistances that hamper the dispersion of the TIS, e.g. oppositions towards the construction of thermochemical conversion plants. The diagnostic questions that could be submitted are the following:

a. Is there an issue of public acceptance against energy crops? If yes, could it be addressed?
b. Is there an issue of public acceptance against biofuels production plants construction? If yes, could it be addressed?
c. Is the legal procedure causing any barrier?
d. What are the activities of lobbying groups or promoting organizations?

2.3 Analysis and scoring of system functions

In this section the strengths and weaknesses of the technology innovation system are evaluated, using the information collected in the previous phase of the TIS analysis. The evaluation is based on performance indicators developed for the BIKE project.

2.3.1 System Analysis

The set of diagnostic questions developed in previous section act as guidelines to research the state of development of the TIS under investigation. In the following paragraphs the information collected by means of the questionnaires addressed to project partners are presented and discussed, for each case study.

2.3.1.1 Biogas done right model (BDR) for biomethane-to-liquid fuels

F1 – Entrepreneurial Experimentation and production
For what concerns this system function, according to CIB, it turns out that the number of actors identified in the structural analysis relevant and sufficient. As a matter of facts, the industrial players are numerous, and the sector is already established. The trend of growth of the actors, i.e. the number of industrial players, is fairly levelling, especially as regards biogas. Some new actors are present in biomethane and liquefied biomethane.
It appears that is no lack of actors in the matter of this case study, thus there are no barriers in the development of the TIS.
Moreover, according to CIB, industrial actors sufficiently focus on large scale production and sufficiently innovate. This position is confirmed by the numbers reported in the annual report provided by the European Biogas Association, and summarized in BIKE deliverable D3.1. The sole weakness identified is concerning the technology providers for biomethane to liquid conversion plants. Despite the technology can be considered well developed, actors are not many, and mainly operating in fossil fuels and chemical sectors.

F2 – Knowledge Development
As regards this function, the information collected through the questionnaire addressed to CIB, reveals that the amount and quality of knowledge development is sufficient for the development of the innovation system and that the type of knowledge developed so far fits with the knowledge needs. Furthermore, an increase in the diffusion of knowledge would benefit the growth of the sector and, above all, the growth of the sector with the right models such as the BRD model. It is definitely essential to make the BDR model known to all stakeholders, and thus CIB is promoting it both at Italian and European level. Communications activities have increased rapidly, and the model is also expanding and improving in Europe. Besides, in accordance with CIB, enough pilot trials are conducted, and indeed in Italy lots of CIB’s member already use the BDR model and other biogas/biomethane plants are replicating it in Europe. Considering the specific process steps involved in this case study, from feedstock production, to anaerobic digestion, biogas purification and biomethane-to-liquid upgrading, the knowledge is widely available at both research, and industrial level. Several studies have been published concerning the Biogas Done

Right model and about gas to liquid conversion technologies. According to J.-P. Lange, 1996[20] numerous process schemes have been proposed for converting methane to liquid hydrocarbon fuels. Economic evaluation studies generally conclude that none except the best of these schemes are attractive at present oil prices of <20 $/bbl. However, this potential could be unlocked by favourable economic conditions.

F3 – Knowledge exchange
Thanks to the information provided by our project partner, and to the data collected in literature, it was possible to get an overview of the type and the amount of networks. It came out that there are numerous workshops and initiatives, both in the field and online, organized by CIB, but also by universities, sectoral associations and industrial actors, which promoting and spreading the BDR model and, more in general, the role of biomethane as Low ILUC risk biofuel The participation is particularly high, from farmers to technology suppliers, to public. For what matters the knowledge exchange between science and industry, in Italy CIB has constant contacts with universities and the main research bodies active in the sector; the same happens for the main trade associations similar to the CIB in Europe. Moreover, as CIB includes more than half of the agricultural biogas plants in Italy and the main technology suppliers, there is a perfect dissemination of knowledge; furthermore, being CIB also a founding member of the EBA (European Biogas Association), the diffusion of the BDR model is eased, so there is certainly sufficient knowledge exchange across different countries, and surely a greater diffusion will accelerate the evolution. Furthermore, in the rest of Europe, there are also other trade associations at national level like CIB, which facilitate the interaction between farmers and industries.

F4 – Guidance of the Search
Switching to the analysis of the motivation of the actors to take part to the growth and propagation of this case study, from the questionnaire addressed to our project partner CIB, it emerges that is there a quite clear vision on how the industry and market should proceed in terms of growth and technological design, and the visions and expectations of actors involved are sufficiently aligned; this means that there are relevant uncertainties and there are no barriers against the development of the case study "Biogas done right model (BDR) for biomethane-to-liquid fuels". As a matter of facts, the technology is ready and tested, substrate potential of biomethane production is studied within the country context, and such a study is available to the actors in the value chain. Of course, the substrate must be sustainable. The motivation of actors to take part to the development of this case study is also fed by the fact that there are national targets and recommendations for biofuels production, and more in detail to substitute a percentage of fossil fuels with biofuels and for vehicle fuel substitution with renewable fuels Anyway, there is no specific mention of governmental policies supporting low ILUC risk biofuels. In particular, the present incentives available in countries like Italy, UK, and other EU member states are strongly supporting the market growth. The uncertainty regarding the incentives scheme and the lack of specific support to Low ILUC risks biomethane compared to conventional one can be a limit towards the development of the TIS

F5 – Market Formation

[20] J.-P. Lange, P.J.A. Tijm, Processes for converting methane to liquid fuels: Economic screening through energy management, Chemical Engineering Science, Volume 51, Issue 10, 1996, Pages 2379-2387, ISSN 0009-2509, https://doi.org/10.1016/0009-2509(96)00094-2

Regarding the market around the case study “Biogas done right model (BDR) for biomethane-to-liquid fuels”, the questions addressed to CIB allowed to state the market size (current and expected) is sufficient, and this means that no barriers for the development of biomethane commercialization to be used to produce synthetic fuels exist. The BDR model can be applied to both the biogas and biomethane sectors. The biogas sector is already developed and widespread, and the biomethane market is growing rapidly. Moreover, there is already a niche, but fast growing market for gaseous fuels in light vehicles. In Italy, the purchase of biomethane is regulated by the certification of origin, which enables consumers to count the “green” fraction of the natural gas consumed from the grid. This advanced development status of the biomethane market in Italy contribute the development of the sector. To promote the development of a biomethane market there are incentives for its production, and even though no specific support schemes for its utilisation are currently planned, the price on fossil CO2 set by the existing European ETS system represents an indirect incentive for end users to increase the consumption rate of biomethane. However, the lack of a long-term incentive system might constitute a barrier. In Italy there is the largest number of methane distributors, equal to 1663.

F6 – Resource Mobilization

Focusing on the resources involved in this case study, from the answers provided by CIB, it turns out that there are sufficient skilled human resources, while financial-wise they must be increased to sustain the growth of the sector. In Italy, as mentioned, a financing decree for biomethane production is active and a new one is being written. In Europe, the situation is different scenarios depending on the country.

Many farmers have already decided to invest in the BRD model and are applying it successfully. This means that this innovation system is currently positively inclining.

Regarding the physical equipment, according to CIB there are enough suppliers for what matters to the biomethane production; regarding the infrastructure present, although the Italian gas network is among the largest in Europe, many biogas and biomethane plants could have problems with distance from the nearest available injection point, increasing connection costs and times. Apart from this aspect, no physical resource mobilization constraints that may hamper technology diffusion is expected, due to the fact that the starting feedstock for anaerobic digestion is cultivated close the biomethane production plants, so it must not be transported to the refinery. The resource to be transported is the biomethane, by means of the existing natural gas grid. However, in EU countries where natural gas grid is less developed and where biomethane injection could be expensive, like Greece, or not possible, the TIS suffers a great infrastructure barrier.

F7 – Counteract resistance to change/legitimacy creation

Let us now consider the perception of the actors involvement along the “Biogas done right model (BDR) for biomethane-to-liquid fuels” case study. According to project partner CIB, as the BRD model uses sequential crops, waste and by-products, it has no particular problems of social acceptability. However, the production of renewable energy and biofuels has historically had many social acceptability problems. The biogas sector has particularly suffered, and therefore CIB is fighting this phenomenon with careful and important planning of communication activities aimed at fighting fake news and spreading knowledge. For what matters legal procedures, there are still some regulatory blocks, such as the lack of regulations for the conversion of biogas plants to biomethane; anyway, it is expected that these will be introduced in the upcoming decree. For what concerns the activities of lobbying groups or promoting organisations, CIB brings together the various players in the supply chain in order to better disseminate knowledge and best practices and act at the political and institutional level.

2.3.1.2 Castor oil for HVO

To assess the system functions related to this case study, project partner ENI has been required to reply to the questions reported in the previous section. The information were integrated with data from literature and from the previous studies performed within WP3. The level of detail of the answers is definitively exhaustive, with a large amount of information especially provided for the Italian context.

F1 – Entrepreneurial Experimentation and production
As regards this system function, according to project partner ENI, the number of actors identified in the structural analysis relevant and sufficient, and besides, the trend of growth of the actors appears to be increasing. Moreover, it turns out that that is no lack of actors in the matter of this case study, thus there are no barriers in the development of the TIS, and indeed integrated energy companies can guarantee access to market and promote sustainable mobility. Furthermore, from the information gathered, industrial actors, e.g. ENI, sufficiently focus on large scale production and sufficiently innovate; in fact, ENI has invested 7 billion euros in the last years in R&D and in development of proprietary technologies.

F2 – Knowledge Development
To assess this system function, several diagnosis questions have been addressed to project partners (ENI and EXERGIA), and a considerable amount of information has been obtained. The innovation system consists in the establishment of Low-ILUC agro-feedstock value chains in Southern Italy (Sardegna), Kenya and Greece. The development status of the technologies involved in the case study is high, thanks to the well development status of castor oil extraction market sector and, in general, of vegetable oil extraction from oleaginose crops. In fact, both plant cultivation, seed harvesting, cleaning and pressing until oil extraction is performed are all well known process steps, already in place in ENI facilities and in other parts of the world. About the transformation of castor oil into HVO, ENI has developed the technology, based on patented know-how and experience already applicated at industrial scale in two operating biorefineries, located in Gela and Venice. The Joint Venture was formed in 2021 between ENI and *Bonifiche Ferraresi*, a leading agricultural group in Italy, with the aim of developing research activities and to provide agronomic know-how on agro-feedstock cultivation (development of improved seed varieties, identification of sustainable agricultural practices etc), technical trainings and field support. Farmers in the selected areas for the case study own already some knowledge and experience on crop rotations and cover cropping, since the cultivation of oleaginous crops (e.g. sunflower) on low fertility, degraded lands is already present. Industrial know-how is also available in the areas of TIS, since there are oil processing plants (for example in Macchiareddu). A minor barrier is represented by the use of castor cake, the by product of castor oil production process, which represent a critical material due to the concentration of ricin. Ricin is a highly toxic ribosome-inactivating lectin occurring in the seeds of castor bean. Due to the presence of the toxin, castor bean can cause death after the exposure of animals to low doses of ricin through

skin contact, injection, inhalation or oral routes[21]. Technologies suitable to detoxify castor cake and enable its use as soil conditioners include chemical treatment, and pyrolysis, to transform castor cake into biochar usable as carbon negative soil conditioner. The knowledge about these practices is evident, even if no industrial experiences have been identified. Solid scientific support to the development of the Innovation System in Italy and in Kenya is provided by Italian universities owning a focus on oil crops, such as University of Bologna, University of Catania, University of Sassari, ensuring data quality and input innovation (suitable seed varieties, agronomic practices, etc) during the implementation of the IS. The knowledge developed by the Innovation System contribute to fill the existing gaps, by defining the yield potential, agronomic practices and lesson learnt for the cultivation of Low-ILUC feedstock on degraded/abandoned/unused lands in Southern Italy. In general, the development of the System is affected by the lack of a clear reference in terms of EU certification scheme framework and technical benchmarks for Low-ILUC crops, which limits the development of supporting technologies as well, such as, for instance, improved seed varieties able to effectively perform on degraded and marginal lands, with low fertility. Let us focus on the possible barriers against the TIS development related to the quality and quantity of the knowledge.

Several research and trials were established by ENI to support the development of the innovation system. The knowledge gained in several locations and within different collaboration framework allowed to gain a relevant knowledge under field conditions of castor bean varieties at national and international level.

In particular:

- A joint research agreement between ENI and the Italian National Research Council (CNR) was signed in 2019 to develop strategic research topics and technological innovation paths to support the development of advanced and low carbon biofuels, within ENI decarbonization strategy plan. One joint agricultural research centre was created (Portici, Naples) to carry out research programs (PhD grants) on the selection of oleaginous varieties suitable for arid, marginal, saline, or contaminated soils, to produce oil, eligible as Low-ILUC, destined to ENI biorefineries.

  Several varieties of castor bean were collected (supplied by ENI, available on the market or collected from spontaneous exemplars on saline and contaminated sites) and compared trough different field trials under different conditions. The results showed that the seeds that grew better were those supplied by ENI.

[21] Sousa, N.L., Cabral, G.B., Vieira, P.M. *et al.* Bio-detoxification of ricin in castor bean (*Ricinus communis* L.) seeds. *Sci Rep* **7,** 15385 (2017). https://doi.org/10.1038/s41598-017-15636-7

Figure 7. Field and pot tests carried out in Portici

- In 2019, ENI and the University of Catania started a joint research program on the genetic improvement of castor bean varieties. The Department of Agriculture, Food and Environment of the University of Catania selected one or more genotypes from the variability existing within a population of castor preserved in Sicily. Selected varieties were further characterized through field trials. The research allowed to identify castor varieties showing promising agronomic characteristics and to expand their cultivation in different environments, such as in pilot trials in Sardinia (2021), with *Bonifiche Ferraresi* (BF). Details are reported below.

Figure 8. Castor plant (Catania, August 2020)

- A field trial was established in 2021 in Bonifiche Ferraresi farm (Marrubiu-Oristano) to perform field tests on castor bean varieties selected by the University of Catania, with the aim of optimizing sustainable agricultural practices. One local improved variety of castor bean (semi-woody large shrub) was planted on an area of about 1 ha, at different sowing distances. During the first year, the crop performances were limited, due to the high temperatures. ENI and BF are currently continuing agricultural testing on castor bean varieties in Sardinia.

Figure 9. Castor field (Sardinia, June 2021)

In addition to the initiatives promoted by ENI, the IS capitalized on the knowledge generated by other actors in the area of implementation, in Sardinia in particular:

- The University of Sassari (Sardinia) conducted a pilot trial in order to explore the potential and adaptability of agro-feedstock minor species in Sardinia (e.g. *Camelina sativa*), within the framework of the BIOPLAT- EU European project (2018- 2021), having the goal to promote and support the uptake of sustainable bioenergy projects on marginal, underutilized and contaminated lands.

Figure 10. Camelina sativa field

- In 2012, AGRIS Sardinia (regional agency for research and innovation in the agricultural sector) presented the results of a study on oleaginous crop varieties, carried out in Sardinia between 2006 and 2011. Experimental trials to compare *Brassicaceae* varieties (*B. Carinata* and *B. Napus*- oilseed rape). Oilseed rape was found to be more productive and oil production per hectare appeared to be closely related to yield.

F3 – Knowledge exchange

The information gathered with the help of ENI show that several dissemination events were regularly held In Italy (and specifically in Sardinia) related to the topic of bioenergy, covering agro-feedstock and sustainable biofuels, to which ENI contributed as invited speaker or as organizer. In particular:

- European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI): Workshop "Building new biomass supply chains for the bio-based economy" May 27 – 28, 2015 – Alghero, Sardinia, Italy;

- Agenzia Regionale LAORE Sardegna: Workshop “Le energie alternative, occasione di sviluppo per l’agricoltura sarda” April 25, 2019 – Arborea, Sardinia, Italy;
- BIOPLAT-EU, Working Group Meeting “Promuovere l’utilizzo sostenibile di aree marginali e sottoutilizzate per la produzione di bioenergia, attraverso una piattaforma telematica per l’Europa” September, 15, 2020 – Cagliari, Sardinia, Italy;
- BIOPLAT-EU Workshop “Il Progetto BIOPLAT-EU e il settore bioenergetico in Sardegna – presentazione e guida all’uso dello strumento STEN” September, 9, 2021 – online.
- Eni is currently organizing a Case Study Field Visit (BIKE project) ENI scheduled on summer 2022. The event will include the field visit to the *Bonifiche Ferraresi* farm, as a show case for the agronomic trials on different oil crops. Moreover, it will serve as a networking and disseminating event to illustrate the activities carried out jointly by ENI and *Bonifiche Ferraresi*, aiming at the development of research on agro-feedstock crops for ENI’s bio-refineries.

All the actors were actively engaged in the workshops and conferences, from European to regional and local level, contributing to knowledge exchange as participants or keynote speakers. Regarding the exchange between science and industry, ENI has used several instruments to support industry-science knowledge transfer (and vice versa) through joint research agreement with universities and research centres in Italy and abroad. The agreements provide for the development of projects and initiatives to support the creation of Low-ILUC agro-feedstock supply chain in Africa and in Italy, in terms of knowledge and technology. The field visit to the Innovation system and the “open air” agronomic lab of *Bonifiche Ferraresi* farm (scheduled for the summer 2022) is part of this effort. Moreover, ENI participates regularly to knowledge networking events (meetings, conferences, etc.), in Italy and abroad through different dedicated departments.
It also appears that there is a good knowledge exchange between users and industry. As a matter of facts, in ENI there is a dedicated communication department in charge of manage the dissemination of information and promotion of activities carried by the different business units. Knowledge for the development of this Innovation System turns out sufficient and effective across the different countries. The active participation of ENI to the BIKE project ensures that the knowledge generated through the IS is shared among all the partners through the Basecamp platform and field events. Within this framework, the aforementioned showcase organized by ENI for the summer of 2022 in Sardinia, presents the activities and the results of the pilot study (field trials, objectives and future steps). Capitalizing on this experience, ENI is also launching a series of joint initiatives in various countries (especially in Africa) to support the development of Low-ILUC agro-feedstock production for the development of local supply chain.
In conclusion, in the light of the partner’s answers, we can certainly assert that knowledge exchange is not forming any barrier for the IS to move to the next phase.

F4 – Guidance of the Search
Let us focus our attention on the motivation of the actors involved in the growth and propagation of the case study under investigation and related mechanisms.
First of all, considering how the industry and market should proceed in terms of growth and technological design, it appears that the vision is clear. Indeed, ENI is combining its biorefining and marketing activities in a subject dedicated to sustainable mobility. The vision includes the growth of the biorefining capacity from 1 to 2 million tonnes per year by 2025. Such growth

requires the expansion of the existing biorefineries and the conversion of a traditional one, with a robust supply of diversified raw materials, which ENI will guarantee thanks to the vertical integration of the business. The company is developing a network of agri-hubs in African countries, with the aim of covering 35% of the supply of its bio-refineries by 2025. In addition, ENI Stations will be redesigned to be a space for customers and enable the access to sustainable biofuel and retail services.

About the prospects of technological field, the achievement of 6 million tonnes per year of biorefining capacity is expected in the next decade, by covering 35% of the biorefinery supply by 2025.

A crucial aspect to be considered to reduce uncertainties is the alignment of the visions and the expectations of the several actors involved in the value chain. In this matter, ENI chooses the vertical integration model for biofuels production to guarantee a sustainable steady supply of vegetable oil to its bio-refineries in Italy. The model entrusts the agricultural production to local small- farmers, cooperatives or large- companies, through contractual arrangements, to supply of raw material. Through the vertical integration model, ENI develops a new share of the market and securitize the feedstock availability in partner countries, reducing the risk compared to open market purchase. The model facilitates the access to market for small farmers, reducing the cost of participating and creating new job opportunities at local level, pursuing sustainable socio-economic development and access to land for rural populations, ultimately contributing to human right protection and food security. Moreover, the Joint venture with *Bonifiche Ferraresi* ensures a full alignment for the technical development of the activities.

Therefore, we can conclude that there is no lack of a shared vision in this case study, and according to ENI common shared vision even represents a strength for the development of the TIS.

Moreover, about the substrate potential for biofuels production, ENI states that Castor is a suitable substrate for the production of biofuels. To reinforce this statement, currently, some castor field trials have been performed in 2021 in Sardinia, as a part of activities of the ENI and *Bonifiche Ferraresi* Joint Venture, established in order to develop agricultural testing of oleaginous seeds to be used as agro-feedstock in ENI biorefineries.

Furthermore, there are no issues about the availability of this case study, as it will be available to the BIKE partners on the Basecamp platform.

For what matters the national targets for biofuels production, the Italian NECP foresees on one hand a reduction of the use of first-generation biofuels up to a maximum share of around 3% by 2030; on the other hand, an increase in the consumption of advanced biofuels is expected, with a target of around 8% (more ambitious than the 3.5% envisaged by 2018/2001/EU Directive), mainly through to the contribution of biomethane, which is expected to represent 75% of the total advanced biofuels (1.1 billion of m^3).There are two measures included in the European recast Renewable Energy Directive to boost low ILUC risk biofuels: firstly, the directive sets national limits of 1 point percentage higher than the 2020 national share of these fuels in final consumption energy in rail and road transport (with a max of 7%) of biofuels, bioliquids and biomass fuels considered "high ILUC" (i.e. produced from food or feed crops); secondly, it sets national limits at Member States' 2019 level for the period 2021-2023 after which, limits will gradually decrease to zero by 2030 at the latest. These limits will affect the amount of these fuels that can be considered when calculating the overall national share of renewables and the share of renewables in transport.

The RED II sets national limits between 2021 and 2023 and a gradual phase out after 2023, for high ILUC-risk biofuels, bioliquids and biomass fuels produced from food or feed crops with a significant expansion into land with high carbon stock, with a target to decrease to zero by 2030 at the latest. The limits affect the amount of these fuels that can be taken into account when calculating the overall national share of renewables in transport. The lack of a well-defined low-ILUC certification system, adequate seeds available to farmers and solid know-how on cover crops is currently a barrier

Italy mandated the use of advanced biofuels through Ministerial Decree on October 10, 2014 (and following amendments) introducing a blending obligation of biofuels for suppliers of fossil fuels. The Italian Ministry of Economic Development amended this mandate with a new decree on December 30, 2020. To comply with the Eu RES target in the transport sector, a quota of 10% of overall biofuel is mandatory. It is relevant to say that a mandatory quota for "advanced biofuels" has been introduced and, according to the provisions of the Ministerial Decree 2nd March 2018, it has been fixed a mandatory quota of 1.875% for advanced biomethane and of 0.625% for other advanced biofuels. The ministerial decree 30th December 2020 introduced a new mandatory quota (0.6%) concerning the supply of advanced biofuels in addition to the existing quotas.

F5 – Market Formation

Turning to the topic of market formation, the market of biofuels and biodiesel is a growing market. In fact, the biofuel global demand is expected to grow from a 130 million of tonnes per year in the 2020, to 180 million tonnes per year in 2030 in the sustainable development scenario of IEA, and to 310 million tonnes per year in the stated policies scenario of IEA. According to ENI, the market size is wide enough to justify the investment in the system.

However, the market of biofuels cannot be considered a niche market because of the levels of the target decided by RED II. All countries in Europe have emanated laws to cover the percentage of 14%, this gives the market high prospective of growth in the next years.

For what matters the incentives for biofuels production, European Commission approves €4.7 billion public support scheme for advanced biomethane and biofuels in Italy. The producers of advanced biofuels, different from advanced biomethane, can obtain from the GSE a premium of EUR 375/CIC for every 5 Gcal of biofuels sold to obliged fuel retailers who participate in the scheme and upon proof submitted by those retailers that the said quantity has been placed in the market for use in transport. Obliged fuel retailers purchase the biofuel at a maximum price linked to fuel prices (based on the average Platt's published levels, minus 5%).

Considering the biofuels filling station infrastructure, biofuels and in particular biodiesel are already present in blends in Italy. Currently, on the market, ENI sells Diesel+, which is a diesel with a 15% presence of HVO produced from its biorefineries through the Ecofining^{TM} technology and available at ENI filling stations, which are present in high number on all the Italian territory. ENI plans to increase its ENI live stations with 1.5 million touchpoints per day.

Regarding vehicles running with biofuels, the market size is projected to reach multi million by 2028, in comparison to 2021. Registrations of alternative-fueled vehicles (methane, LPG, biofuels, ethanol) increased by 10.2% in 2021, reaching 21,340 fuel units across the EU. Therefore, vehicles running with biofuels can be considered as a growing segment on the market.

F6 – Resource Mobilization

As regards the mobilization of a set of resources (human, financial and physical), it appears that the skilled labour is sufficient, or at least it will be soon. As mentioned, ENI and *Bonifiche Ferraresi*, the largest Italian farm in terms of utilized agricultural surface area, have formed a joint venture in order to develop research projects and agricultural testing of seed of oil plants to be

used as agro-feedstock in ENI biorefineries. The joint venture will also focus on the development of training programs for personnel for agro-feedstock project development sectors.
For what matters the projects funded by Governments, in Italy the ecological transition is recognized as an important issue; therefore, incentives will be granted in the next years to ensure the EU target by 2030 will be reached. The European Commission has approved under EU State aid rules an Italian support scheme for the production and distribution of advanced biofuels, including advanced biomethane. The Italian scheme supports the production and distribution of advanced biofuels and advanced biomethane, also known as second and third-generation biofuels, for use in the transport sector. As previously reported, this scheme has an indicative budget of €4.7 billion and will run from 2018 until 2022.
For what matters tax benefits and investment subsidies on vehicles running with biofuels, in 2022, the Ministry of Economic Development in Italy will issue in the next months a series of incentives, that as of today are still in form of a draft, to sustain the automotive sector that will help consumers to buy vehicles of a more ecological kind. This incentive, given the energy transition prospect, will apply to electric vehicles, but also to gasoline and diesel. The bonuses will be divided into three groups based on CO2 emission produced, the one interesting diesel will be the group 61-135 grams that could receive around 3 thousand euros but only for vehicles registered Euro 6. The incentives are still under discussion. Other financing options will optimistically be available in the next years.
About the physical infrastructure, and the mobilization of physical resources, the conditions of the plant in identified sites like Sardinia and Kenya are adequate to support the project logistic; the same can be said for Italy general infrastructure development and sea shipping is a total functioning option to deliver the product in all the Italian territory. It must be underlined that, in comparison with petrol oil supply chain, the production of vegetable oil is distributed in more extraction sites, each of them ensuring a limited production. Moreover, the transportation of the extracted vegetable oil can have an impact on the cost of the final product. Therefore, an efficient supply chain must be always developed and, in some cases, it can represent a slowing factor against the development of this TIS.

F7 – Counteract resistance to change/legitimacy creation

Let us focus now on the legitimacy and the eventual resistances related to this case study. According to ENI, the public acceptance against energy crops might be an issue, as the main critic/misconception in the public regarding energy crops is that they are a direct competitor with the food chain and not being sustainable. Following the low-ILUC guidelines, the project assures to be sustainable, not compete with the food chain and lower the emission of CO_2, and therefore the issue of public acceptance could be addressed. Anyway, there is no information about complaints in building oil extractors, whereas the conversion of refineries into biorefineries has been seen as a positive event.
For what matters legal procedures, getting the certification of low ILUC biofuels is not an easy process and need to respect strict criteria, not being able to obtain this certificate could be a barrier in the production of more sustainable biofuels.
About the activities of lobbying groups and promoting organisations, the general opinion on biofuels is positive, also thanks to the support (in Italy) of the Ministry of Economic Development and their production has been addressed by the Minister himself in 2022. The European Union support the increase of this market with its Directive and by promoting the Green Deal and the sustainable transition, claiming biofuels as a necessary step for decarbonization in Europe.

2.3.1.3 Brassica Oil crops for renewable diesel

The functional analysis of this case study has been assessed thanks to the answers provided by project partner UPM to the questionnaire reported above.

F1 – Entrepreneurial Experimentation and production

As reported in the structural analysis, similarly to the value chain on castor cultivation for Low ILUC HVO production, the value chain characterizing this TIS can count of a sufficient number of actors. In particular, for what matters this system function, farmers to be potentially involved in the production of Brassica as feedstock for the production of renewable diesel are available; this agricultural practice is considered doable by farmers; however, the specific practice of cultivating brassica in cover cropping is still not really developed in EU countries, mainly for the lack of a market demand.

According to UPM, leading the market of renewable diesel from brassica oil, the industrial actors involved sufficiently focus on large scale production. In addition, as for castor oil, the actors operating in the value chain steps of oil extraction, storage, and refining are available. However, despite a wide network of agricultural and biofuels associations, this TIS is not yet adopted at EU level. , especially in innovative sustainable land use concepts (e.g., low ILUC risk biofuels). For this reason, entrepreneurial experimentation can be considered high, but the production in Europe is low, and this can be due to the lack of support from institution and, in particular, from the weak regulative framework which limits the scaling up. In general, the amount of information gathered appears to be not abundant; this means that some uncertainties are present in the case study..

F2 – Knowledge Development

Let us consider now the knowledge developed around the Innovation System under investigation.

The scientific and technological knowledge concerning Brassica Carinata cultivation for oil production is considered sufficient and well developed. The case studied identified in the context of WP6 about Brassica Carinata cultivation experiences in Italy, Greece, demonstrate that agronomic practices, as well as oil extraction and refinery trials have been successfully carried out. Publications related to Brassica Carinata cultivation for biofuels production reported clearly how species like the white mustard, native to the circum-Mediterranean region could be easily cultivated by companion planting to improve ecosystem function by decreasing soil loss, controlling microbial disease, and assisting in the maintenance of biodiversity[22]. Production and operating knowledge has been also proven by experiences in Sicily, Apulia, and Greece, where plantations are still in place.

Application-specific knowledge. Additionally, the industrial experience gained by BIKE partner UPM in Uruguay, over thousand hectares of cultivation of Brassica as cover crop enabled to provide new evidence on the methodology and definitions around this specific low ILUC risk biofuel. As reported by ENI, other studies may constitute important references, such as the

[22] Jaime R, Alcántara JM, Manzaneda AJ, Rey PJ. Climate change decreases suitable areas for rapeseed cultivation in Europe but provides new opportunities for white mustard as an alternative oilseed for biofuel production. PLoS One. 2018 Nov 5;13(11):e0207124. doi: 10.1371/journal.pone.0207124. PMID: 30395645; PMCID: PMC6218090.

above-mentioned study of AGRIS Sardinia (2012), which compared *Brassicaceae* varieties (*B. Carinata* and *B. Napus*- oilseed rape).
Enough pilots are also periodically conducted by UPM to test how the certification process works technically, however a more limited knowledge is available concerning how the low ILUC risk biofuel will impact the systemic change in the transportation fuels sector. This lack of sufficiency of strategic knowledge constitutes a barrier for the TIS development.

Figure 11. Brassica Carinata field

F3 – Knowledge exchange
According to project partner UPM, despite the technical knowledge and the industrial experience available on this TIS, so far not enough workshops have been organised to support effective knowledge sharing and coordination between different workstreams. However, there have been some participants from each partner, even though the amount of dialog during the meetings could be encouraged further to maximise the information sharing. Regarding the knowledge exchange between science and industry, UPM asserts that this is taking place and improving gradually, but it can't still be considered enough for a rapid development of the TIS. The case studies could have been developed together more on scientific foundation from the beginning, but work and deeper cooperation has just recently started. About the knowledge exchange between users and industry, UPM argues not to be aware of any specifically linking to Brassica case study. However, the knowledge exchange across different countries is sufficient, as the relevant information of the different case studies in different countries has been shared. In conclusion, there are still some barriers related to knowledge exchange existing, but it has improved recently. In this matter, UPM encouraged to focus to share the relevant scientific data to get best out of the pilot studies. BIKE project could play a key role in improving this aspect of the TIS.

F4 – Guidance of the Search
About the vision on how the industry and market should proceed in terms of growth and technological design, as introduced above, the role of a low ILUC risk biofuel seems to be still

relatively vaguely described, and this could limit the growth of the low ILUC risk biofuels. In particular, despite the technology adopted for feedstock conversion into HVO is clear, about the feedstock production there still uncertainty about the most sustainable and profitable practices, also in the context of the EU and international policy supporting measures. For example, the calculation system for the benefits of performing carbon farming practices on the final CO2 balance of biofuels production system is still unclear. For this reason, UPM highlighted that there technology as such is not as a critical element for this “low ILUC risk biofuel pilot case” because the needed technology for considered (vegetable oil) concept already exists. According to CIB, the visions and expectations of actors involved is not sufficiently aligned to reduce uncertainties; the regulation focuses on capping the high ILUC risk but there is no aligned vision, expectations nor incentives to produce low ILUC risk biofuel in industrial scale. This lack of shared vision constitutes, in some extent, a limitation for the development of this IS. If the status of low ILUC risk biofuel remain vaguely described, it does not encourage production in bigger industrial scale. The pilots focus on provide technical view for the certification but not the vision how ILUC risk biofuels should be interpreted in the future policy frameworks for example.

The substrate potential for biofuels production has been studied by UPM and the results show that there is potential; however, low ILUC risk biofuels are not specifically recognised in any country, and this creates a certain risk to utilise the full potential of this type of feedstock. The substrate potential studies were only internal; thus the results are not available externally.
Turning to the policies supporting the growth and propagation of the TIS, in EU level there are targets to utilize biofuels (RED mandate), but there is no clear policy to support low ILUC risk biofuels, as the RED focuses to phase out high ILUC risk biofuels only. If there are no clear incentives linked to the low ILUC risk biofuel, the whole concept will remain too vague, and it is not motivated to apply.

F5 – Market Formation
Similarly to what reported for the TIS on Castor Oil, the HVO market is well developed and end users are already producing relevant amounts of this type of biofuel in fully operating biorefineries. However, the role of Low ILUC risk feedstock analysed in this study (Brassica as cover crop, and Castor cultivated in arid land) is still representing a niche market compared to the large amounts of UCO and palm oil consumed so far. As a summary In line with UPM position, the market for HVO is formed and end users exists, however, the production of this product from Low ILUC risk feedstock is still not in place, due to the less favourable economic conditions available so far, and to the lack of competitiveness with other feedstock like UCO and Palm Oil. Currently there is no specific market for low ILUC risk biofuels, but if biomass feedstock cultivated on arid land, like the TIS on Castor will be supported as sustainable Low ILUC risk practices, there is no insight that cover crops like Brassica would be supported by the current regulations. The purpose of low ILUC risk raw materials is not defined properly in regulation. This can create a barrier for the whole value chain specifically continue with low ILUC risk biofuel development. As regards low ILUC risk biofuels from Brassica oil crops specific applications, there is no finance incentives for their production and utilization. In general, it can be stated that market for HVO as sustainable biofuel is formed and well established; however, there is still uncertainty about the real market demand and economic potentials of an HVO produced from vegetable oil obtained from Brassica Carinata cultivated as cover crop.

F6 – Resource Mobilization

Let us focus now on the resources involved in this case study. According to UPM, there are enough skilled human resources and financial resources. In addition, supply chain for vegetable oil to biorefineries is already established thanks to the traditional biofuels production sector. Nevertheless, Government funding projects in this sector are still not enough for Low ILUC risk biofuels, and the status of access to financing options is not known. In accordance with UPM, it is possible to state that the physical infrastructure is developed enough to support the diffusion of technology, and its market growth, as the pilot case focuses on Brassicas and further vegetable oils that are based on the existing technology adopted to make biofuels.

F7 – Counteract resistance to change/legitimacy creation
Coming to the public acceptance of energy crops, they are constantly debated, and it is developing to the direction that feedstock should be advanced feedstock, waste/residue or it should meet the additionality requirements, meaning it should not require more land or reduce the food/feed production. Therefore, new sustainable land use concepts such as low ILUC risk raw materials should be further developed to bring acceptance for biomass usage for energy. Public acceptance with regards to the construction of biofuels production plants is like building any new industry, therefore it is not clear whether there would be issues. According to UPM, building new wind farm it is much more debated in public discussion and there can be more resistance for those. Anyway, there are no legal procedures causing barriers specifically for brassicas.
For what matters lobbying groups or promoting organizations, there are some activities involving industrial actors and umbrella association, engaging with EU and national policy makers to ensure sufficient sustainable raw material pool to be available, and support higher mandates for biofuels share.

2.3.1.4 Perennial crops for lignocellulosic bioethanol

The system functions related to this case study have been assessed by means of the experience of RE-CORD and the help of project partners (ICL, EXE, AKI) and experts in this sector which replied to the diagnosis questions reported in the previous section.

F1 – Entrepreneurial Experimentation and production
The actors analysed in the structural analysis appear to be sufficient and relevant for the development of case study “Perennial crops for bioethanol”, and their trend of growth is slightly inclining. Anyway, the lack of farmers, mainly due to the lack of demand, might constitute a forming a barrier for the development of the bioethanol from perennial crops production chain. Even though industrial actors focus sufficiently on large scale production, it seems that they do not innovate sufficiently.

F2 – Knowledge Development
As regards the amount and the quality of knowledge development for the development of the innovation system, we can say that they are presumably sufficient, and that the type of knowledge developed mostly fits with the knowledge needs within the case study. However, it a lack of knowledge can be identified among farmers, but it is not considered a strong barrier for the market. Anyway, enough pilot trials have been carried out.

F3 – Knowledge exchange

Let us consider now the function related to the type of networks involved in the value chain. There have been many conferences during the last years dedicated to the topic of cellulosic bioethanol, with thousands of participants. The knowledge exchange between science and industry is good; however, if we consider farmers among the industry, we must say that this knowledge exchange should be improved. As regards the knowledge exchange between users and industry, we can say that it is sufficient, as it is also between different countries; this issue is in fact common at EU level. In conclusion we can say that the knowledge exchange referred to the low-ILUC aspect is getting more and more visible in the biofuels sector.

F4 – Guidance of the Search

Concerning the motivations of the actors taking part of the development of this cast study, we can say that there is clear vision on how the industry and market should proceed in terms of growth and technological design, as EU targets are definite. The expectations in this field are a technological improvement in pre-treatment, enzymatic hydrolysis, fermentation, and distillation must be investigated further to increase the economic and environmental efficiency of lignocellulosic bioethanol production[23]. Moreover, the actors involved in the lignocellulosic ethanol production are aligned about the urgencies and uncertainties to be solved towards the development of the value chain, according to Epure.

In the light of the information provided, there are no barriers for the development of the TIS related to a lack of shared vision.

The lignocellulosic biomass potential has been widely assessed in many studies, which are available to the actors in the value chain.

For what matters policy-related aspects, as mentioned WP5 reports detailed information. The targets for biofuels production are not so much ambitious. As regards the substrate usage, first generation high ILUC risk feedstocks are not included (Sunflower, rapeseed oil, etc..).

F5 – Market Formation

Let us focus now on the mechanisms related to the market aroused from the TIS under investigation. As for the other case studies of the project, the current and expected future market size can be considered as relevant, even though the growth is not rapid due to the incoming electric vehicles. Anyway, the market size does not constitute a barrier for the development of the TIS in focus. As regards niche markets, even though not properly "niche", we can mention the advanced chemicals production (ethylene, polyethylene, etc..).

Concerning the finance incentives related to biofuels production, the first Delegated Act (European Commission, 2021 b) arising from the Taxonomy Regulation) includes economic activities linked to biomass production and use. Notably: forestry (afforestation, reforestation, forest management, conservation forestry); and the production of energy from biomass. The Delegated Act criteria for Forestry and for Bioenergy are foreseen for review 'based on upcoming Commission policies and considering legislation (including the revision of the Renewables

[23] https://reader.elsevier.com/reader/sd/pii/S0960852421016345?token=50DC934F19E7458D74E9EDDDD1B83951D8CF1A439C2DCA5F95708EDA9E24688C2C595A2F1003DD419D568191511AC4A6&originRegion=eu-west-1&originCreation=20220608083733

Directive), in accordance with the biodiversity and climate neutrality ambitions of the Union (European Commission, 2021)[24].
The finance incentives for biofuels utilization do not include light vehicles.
For that matters the bioethanol filling infrastructure, no specific filling stations are needed, as blending is already available. The sector of vehicles running with biofuels has the same size of conventional fuels. However, bioethanol market is growing slowly (3.5% year).

F6 – Resource Mobilization
Let us now analyse the mobilization of the resources related to the case study.
To the best of our knowledge, skilled human resources turn out to be sufficient for the development of the technology innovation system under investigation, and the financial resources are mainly represented by the Green Deal. Regarding Government funding projects in the sector, research and demonstration projects have been implemented and some of them are ongoing. By the way, there are not tax benefits or investment subsidies for final customers using vehicles running with biofuels. Moreover, the status of financing options is complicated depending on the countries.
Let us now focus on the physical infrastructure for the support for the diffusion of this technology. About biomass availability and supply, infrastructure is already available. The development status depends on the biomass type: it is less effective for residual biomass but it is more effective for cultivated forestry biomass.
We are not aware about expected physical resource constraints that may hamper the technology diffusion.

F7 – Counteract resistance to change/legitimacy creation
Concerning this system function let us see how the perception of the actors involvement along the value chain “Perennial crops for bioethanol” is. From our experience and analysis, we can say that there is no issue of public acceptance against low ILUC risk energy crops. Besides, the issue of “Not in my backyard” can be applied to any processing industrial plant. In Italy this is a relevant problem, while it is less problematic in the other European countries. For sure, a stricter barrier exists against fossil fuels refinery. As regards legal procedures, we can state that complicated procedures constitute a barrier for any sector, and therefore no specific disadvantage is considered with regards to bioethanol from perennial crops, especially if compared to fossil fuels. By the way, we are not aware weather activities of log lobbying groups of promoting organizations are going on.

2.3.2 Development of performance indicators

The set of diagnostic questions corresponding to each system function can be further condensed in form of performance indicators.

System Function	*Performance Indicator*
F1 – Entrepreneurial Experimentation and production	Sufficiency of actors within each category in the value chain
	Growth rate of actors within value chain
	Industrial actors’ contribution to technology innovation

[24] https://ieep.eu/uploads/articles/attachments/a14e272d-c8a7-48ab-89bc-31141693c4f6/Biomass%20in%20the%20EU%20Green%20Deal.pdf?v=63804370211

F2 – Knowledge development and diffusion	Knowledge development (quality, quantity, ongoing research activities) within the value chain
	Sufficiency of pilot trials
	Technology readiness
F3 – Knowledge exchange	Knowledge exchange
	Frequency of conferences and workshops
	Participation of actors within conferences and workshops
	Accessibility and availability of studies
F4 – Guidance of the Search	Clarity of vision on industrial and market proceedings
	Policies on substrate usage regulation
	National targets
	Governmental policies in support of the TIS development
	Policies on substrate usage regulation
F5 – Market Formation	Existing market size
	Perspectives for market uptake
	Financial incentives
	Role of biofuels in the energy mix
F6 – Resource mobilization	Availability of skilled human resource
	Financial resources
	Government funding of research projects
	Access to financing option
	State of current infrastructures/distribution
F7 – Counteract resistance to change/legitimacy creation	Public acceptance of energy crops related to this case study
	Public acceptance of biofuels related to this case study
	Ease of legal procedures
	Activities/contribution of lobbying groups

Table 4. Performance indicators

2.3.3 Evaluation and spider-graph development

In this section, the data collected and analysed for each case study in the previous steps are condensed using the above determined performance indicators, and rated using a scale from 0 (weak) to 10 (very good) in order to enable a more accurate scoring of each function. The questionnaire with all system functions questions was sent to industrial stakeholders: CIB, ENI, UPM, and an external actor in lignocellulosic ethanol production: VERSALIS. RE-CORD scored the performance indicators and the related functions on the basis of: the answers provided by the stakeholders, the previous study conducted in task 3.1, and on literature research.

Moreover, RE-CORD circulated the scoring table (shown above as **Table 4**) to BIKE scientific experts, to receive their feedback too. The average of the resulting votes provided by experts was included and compared with stakeholders feedback result.

2.3.3.1 Biogas done right model (BDR) for biomethane-to-liquid fuels

Table 5 reports the results of the evaluation of indicators done by RE-CORD, the average scores by scientific experts, and the related average of the two. The evaluation is visualized as a spider-graph in **Figure 12**Figure 12.

Table 5. "Biogas done right model (BDR) for biomethane-to-liquid fuels" performance indicator scoring table

System Function	*Performance Indicator*	*Industrial Stakeholders*		*Partners Average*		*Average*
F1 – Entrepreneurial Experimentation and production	Sufficiency of actors within each category in the value chain	8.5	8.2	9	7.3	7.8
	Growth rate of actors within value chain	7		3		
	Industrial actors' contribution to technology innovation	9		10		
F2 – Knowledge development and diffusion	Knowledge development (quality, quantity, ongoing research activities) within the value chain	8.5	8.8	9	8.7	8.8
	Sufficiency of pilot trials	9		7		
	Technology readiness	9		10		
F3 – Knowledge exchange	Knowledge exchange	9	9	9	8.5	8.8
	Frequency of conferences and workshops	8.5		7		
	Participation of actors within conferences and workshops	9		9		
	Accessibility and availability of studies	9.5		9		
F4 – Guidance of the Search	Clarity of vision on industrial and market proceedings	8	8	5	6.0	7.0
	Policies on substrate usage regulation	8		7		
	National targets	7		7		
	Governmental policies in support of the TIS development	9		5		
F5 – Market Formation	Existing market size	9.5	8.875	6	7.25	8.1
	Perspectives for market uptake	9		9		
	Financial incentives	8.5		6		
	Role of the target biofuel in the energy mix	8.5		8		
F6 – Resource mobilization	Availability of skilled human resource	9	8	7	7.2	7.6
	Financial resources	7		6		
	Government funding of research projects	8		8		
	Access to financing option	7.5		7		

	State of current infrastructures/distribution	8.5		8		
F7 – Counteract resistance to change/legitimacy creation	Public acceptance related to this case study	8	8.5	8	6	7.3
	Public acceptance of biofuels related to this case study	8.5		8		
	Ease of legal procedures	8.5		3		
	Activities/contribution of lobbying groups	9		5		

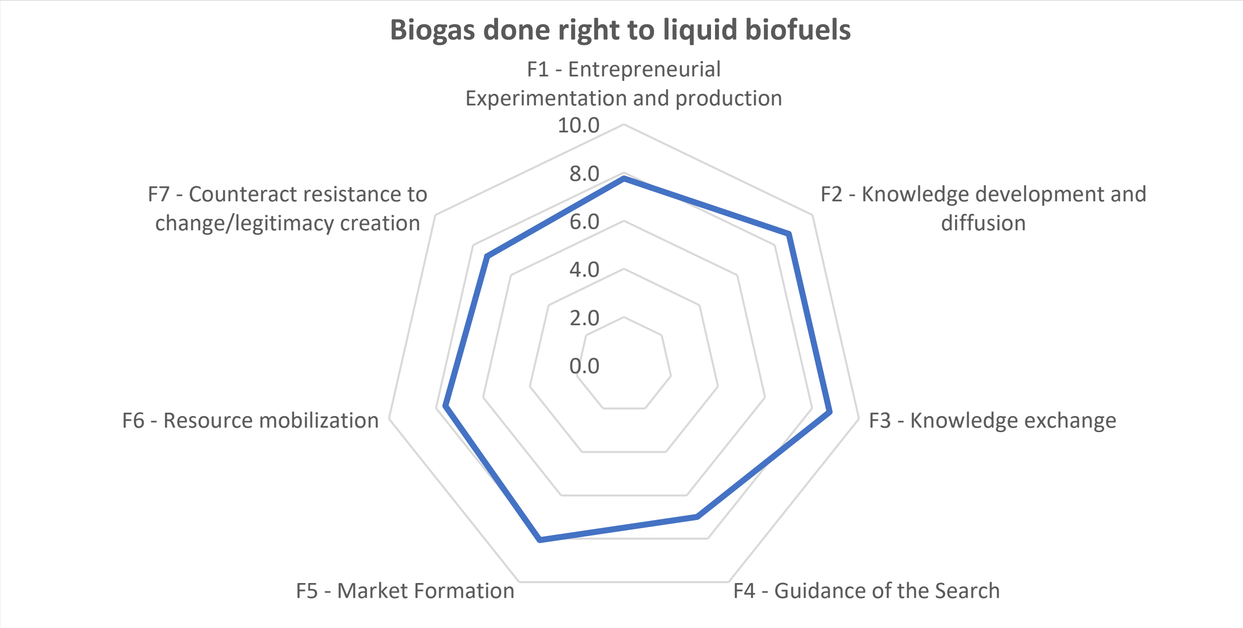

Figure 12. "Biogas done right model (BDR) for biomethane-to-liquid fuels" spider-graph

The analysis showed that this case study is satisfactorily developed with respect to most of the system functions considered for the investigation. The knowledge exchange (F3) is particularly favourable, as well as the market formation (F5). The technology turned out to be well developed, with sufficiency of pilot trials and accessibility of available studies, along with the industrial actors' participation and contribution to innovation, Governmental supporting policies, and availability of skilled human resources. Moreover, the size of the existing market in regards of this case study is already relevant. Anyway, the main limitations have been found in terms of Guidance of the Search (F4) and Resources Mobilisation (F6). National targets, financial resources, and accessibility to financing options should be better managed to achieve a full establishment of the case study. However, these limitations do not constitute a strong barrier to the development of the case study, as the evaluation is nevertheless positive (above 7/10).

2.3.3.2 Castor oil for HVO

Table 6 shows how the performance indicators have been scored by RE-CORD as regard case study "Castor oil for HVO", according to the information collected through questionnaires to project partners, experts and literature review.

Table 6. "Castor oil for HVO" performance indicator scoring table

System Function	Performance Indicator	Industrial Stakeholders		Experts average		Average
F1 – Entrepreneurial Experimentation and production	Sufficiency of actors within each category in the value chain	8	8	9	7.33	7.7
	Growth rate of actors within value chain	7		3		
	Industrial actors' contribution to technology innovation	9		10		
F2 – Knowledge development and diffusion	Knowledge development (quality, quantity, ongoing research activities) within the value chain	9	8.7	9	8.7	8.7
	Sufficiency of pilot trials	8		7		
	Technology readiness	9		10		
F3 – Knowledge exchange	Knowledge exchange	8.5	8.375	9	8.5	8.4
	Frequency of conferences and workshops	8		7		
	Participation of actors within conferences and workshops	8		9		
	Accessibility and availability of studies	9		9		
F4 – Guidance of the Search	Clarity of vision on industrial and market proceedings	7.5	5.75	5	7	6.4
	Policies on substrate usage regulation	6		7		
	National targets	4.5		7		
	Governmental policies in support of the TIS development	5		9		
F5 – Market Formation	Existing market size	9	7.375	6	7.25	7.3
	Perspectives for market uptake	7.5		9		
	Financial incentives	6		6		
	Role of biofuels in the energy mix	7		8		
F6 – Resource mobilization	Availability of skilled human resource	9	7.1	7	7.2	7.2
	Financial resources	5		6		
	Government funding of research projects	6		8		
	Access to financing option	6.5		7		
	State of current infrastructures/distribution	9		8		
F7 – Counteract resistance to change/legitimacy creation	Public acceptance of this case study	8	8.125	8	6	7.1
	Public acceptance of biofuels related to this case study	7.5		8		
	Ease of legal procedures	8		3		
	Activities/contribution of lobbying groups	9		5		

The spider graph produced by the scoring table is shown in **Figure 13**.

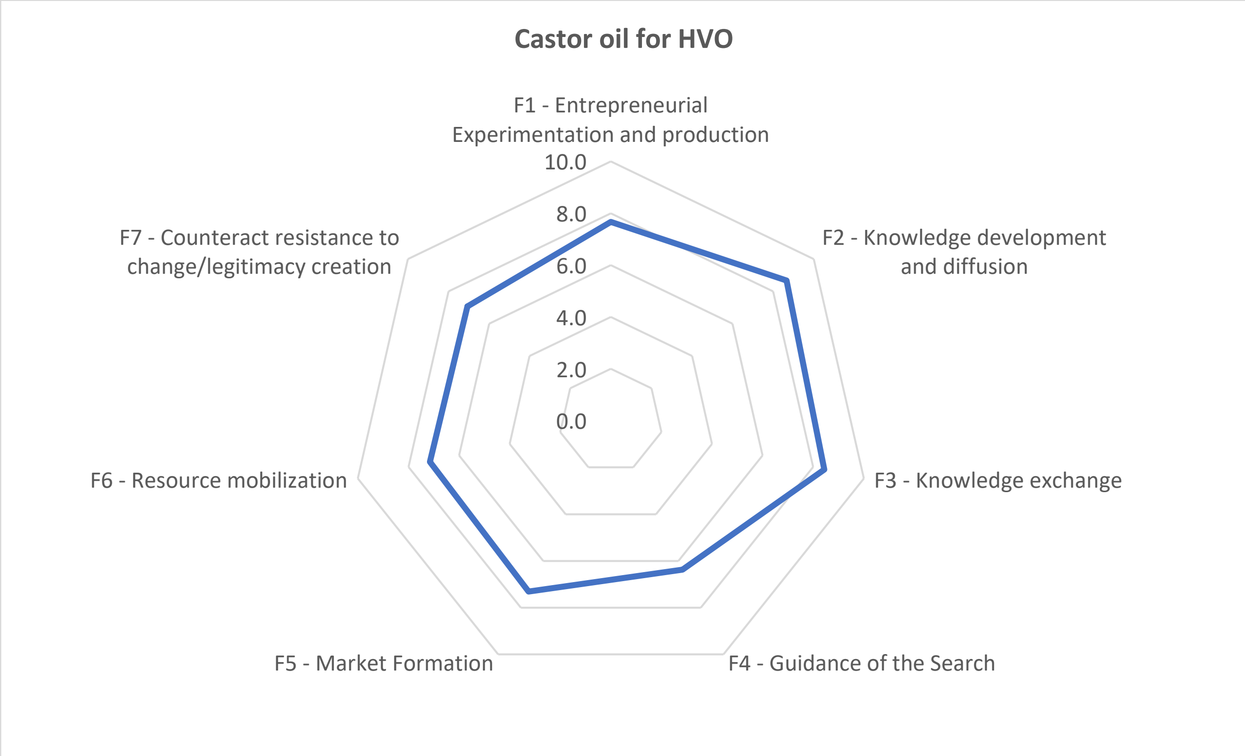

Figure 13 ."Castor oil for HVO" spider-graph

The analysis performed showed that this case study is relatively well developed with regards to functions Knowledge development (F2), Knowledge exchange (F3), Counteract resistance to change/legitimacy creation (F7), and Entrepreneurial Experimentation and production (F1).
The technology turned out to be well developed, with a good quality and quantity of knowledge development within the value chain, with a good accessibility to studies carried out. Moreover, there is a remarkable industrial actors' contribution to innovation, along with a high availability of skilled human resources and a good state of existing infrastructure. In addition, the size of the existing market in regards of this case study is already relevant.
However, some limitations have been found in terms of Guidance of the Search (F4), whose average score turned out to be less than 6/10 according to the industrial actors In fact, there are no strong National targets and Governmental policies in support of the TIS development. Furthermore, the Resources Mobilisation (F6), financial resources, and accessibility to financing options should be better managed to achieve a full establishment of the case study.

2.3.3.3 Brassica oil crops for renewable diesel

Table 7 reports the results of the evaluation for case study "Brassica oil crops for renewable diesel" done by RE-CORD, the average scores by scientific experts, and the related average of the two.

Table 7. "Brassica oil crops for renewable diesel" performance indicator scoring table

System Function	***Performance Indicator***	***Industrial Stakeholders***		***Experts average***		***Average***
F1 – Entrepreneurial Experimentation and production	Sufficiency of actors within each category in the value chain	7	7.5	9	7.3	7.4
	Growth rate of actors within value chain	6.5		3		
	Industrial actors' contribution to technology innovation	9		10		
F2 – Knowledge development and diffusion	Knowledge development (quality, quantity, ongoing research activities) within the value chain	8.5	8.5	9	8.7	8.6
	Sufficiency of pilot trials	8		7		
	Technology readiness	9		10		
F3 – Knowledge exchange	Knowledge exchange	8	8.25	9	8.5	8.4
	Frequency of conferences and workshops	8		7		
	Participation of actors within conferences and workshops	7.5		9		
	Accessibility and availability of studies	9.5		9		
F4 – Guidance of the Search	Clarity of vision on industrial and market proceedings	4	4.875	5	6	5.4
	Policies on substrate usage regulation	5		7		
	National targets	4.5		7		
	Governmental policies in support of the TIS development	6		5		
F5 – Market Formation	Existing market size	9	7.625	6	7.25	7.4
	Perspectives for market uptake	7.5		9		
	Financial incentives	6.5		6		
	Role of biofuels in the energy mix	7.5		8		
F6 – Resource mobilization	Availability of skilled human resource	9	7.5	7	7.2	7.4
	Financial resources	7		6		
	Government funding of research projects	7.5		8		
	Access to financing option	6		7		
	State of current infrastructures/distribution	8		8		
F7 – Counteract resistance to change/legitimacy creation	Public acceptance of crops related to this case study	9	8.375	8	6	7.2
	Public acceptance of biofuels related to this case study	8		8		
	Ease of legal procedures	9		3		
	Activities/contribution of lobbying groups	7.5		5		

The result of the scoring activity is summarized in the spider graph shown in **Figure 14**.

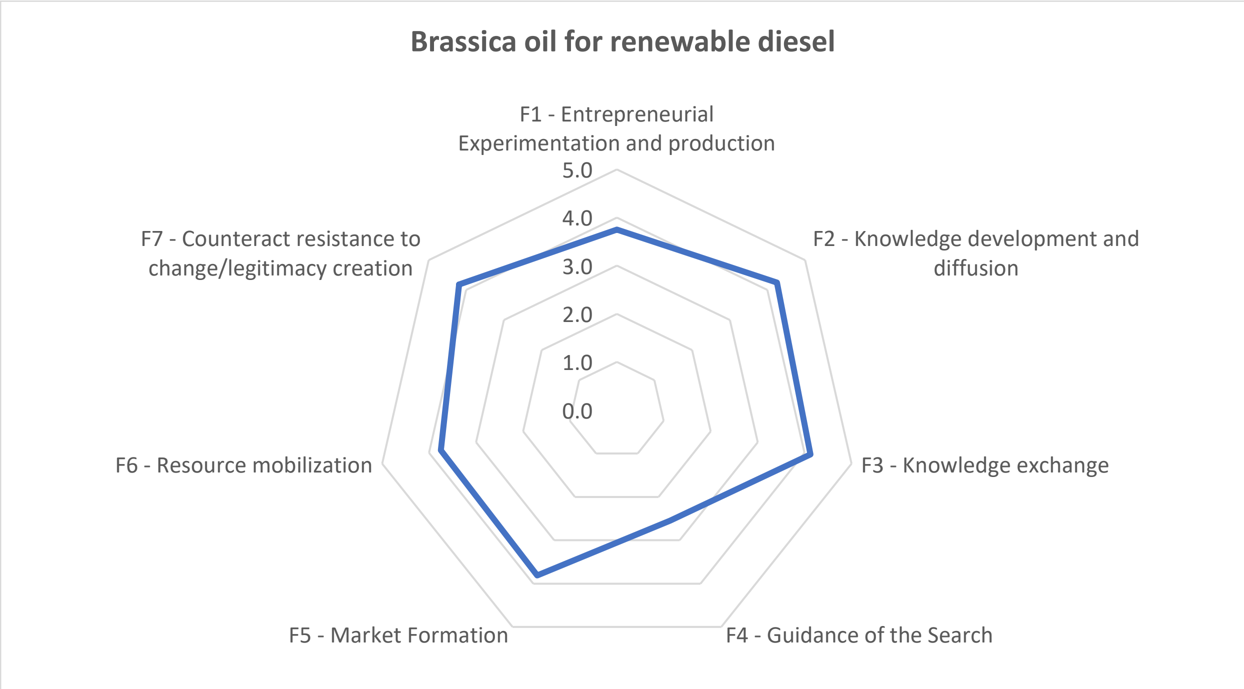

Figure 14. "Brassica oil crops for renewable diesel" spider-graph

The analysis carried out showed that case study "Brassica oil crops for renewable diesel" is relatively well developed with regards to functions Counteract resistance to change/legitimacy creation (F7), Knowledge development and diffusion (F2), and Knowledge exchange (F3).
The technology turned out to be well developed, with a satisfying quality and quantity of knowledge development within the value chain, with a very good accessibility to studies carried out. Moreover, there is a remarkable industrial actors' contribution to innovation, along with a high availability of skilled human resources and a satisfying state of existing infrastructure. In addition, the size of the existing market in regards of this case study is already relevant, and there is a favourable public acceptance of the energy crops related to this case study, as well as the ease of legal procedures.
By the way, some limitations have been found in terms of Guidance of the Search (F4), whose average score turned out to be below 6/10 for all actors involved. In fact, it turned out that there is not a clear vision on industrial and market proceedings, and besides there are no strong National targets and Governmental policies in support of the TIS development. Furthermore, the accessibility to financing options should be better managed to achieve a complete establishment of this case study.

2.3.3.4 Perennial crops for bioethanol

Table 8 shows the scored performance indicators as regards case study "Perennial crops for bioethanol", resulting from the information collected through questionnaires to project partners, experts and literature review. The evaluation is also visualized as a spider-graph in **Figure 15**.

Table 8. "Perennial crops for bioethanol" performance indicator scoring table

System Function	Performance Indicator	Industrial Stakeholders		Experts Average		Average
F1 – Entrepreneurial Experimentation and production	Sufficiency of actors within each category in the value chain	8	7.7	7.8	6.92	7.29
	Growth rate of actors within value chain	7		4.0		
	Industrial actors' contribution to technology innovation	8		9.0		
F2 – Knowledge development and diffusion	Knowledge development (quality, quantity, ongoing research activities) within the value chain	8	8.0	9.0	8.75	8.38
	Sufficiency of pilot trials	9		8.0		
	Technology readiness	7		9.3		
F3 – Knowledge exchange	Knowledge exchange	6	9	9.0	8.8125	8.9
	Frequency of conferences and workshops	10		8.5		
	Participation of actors within conferences and workshops	10		8.5		
	Accessibility and availability of studies	10		9.3		
F4 – Guidance of the Search	Clarity of vision on industrial and market proceedings	4	5.5	5.5	5.9375	5.7
	Policies on substrate usage regulation	7		7.0		
	National targets	4		6.8		
	Governmental policies in support of the TIS development	7		4.5		
F5 – Market Formation	Existing market size	8	7.75	7.5	7.25	7.5
	Perspectives for market uptake	9		8.0		
	Financial incentives	7		6.0		
	Role of biofuels in the energy mix	7		7.5		
F6 – Resource mobilization	Availability of skilled human resource	8	7	8.5	6.9	7.0
	Financial resources	7		6.3		
	Government funding of research projects	7		7.0		
	Access to financing option	6		5.8		
	State of current infrastructures/distribution	7		7.0		
F7 – Counteract resistance to change/legitimacy creation	Public acceptance of crops related to this case study	5	5	7.5	5.875	5.4
	Public acceptance of biofuels related to this case study	7		7.0		
	Ease of legal procedures	3		3.5		
	Activities/contribution of lobbying groups	5		5.5		

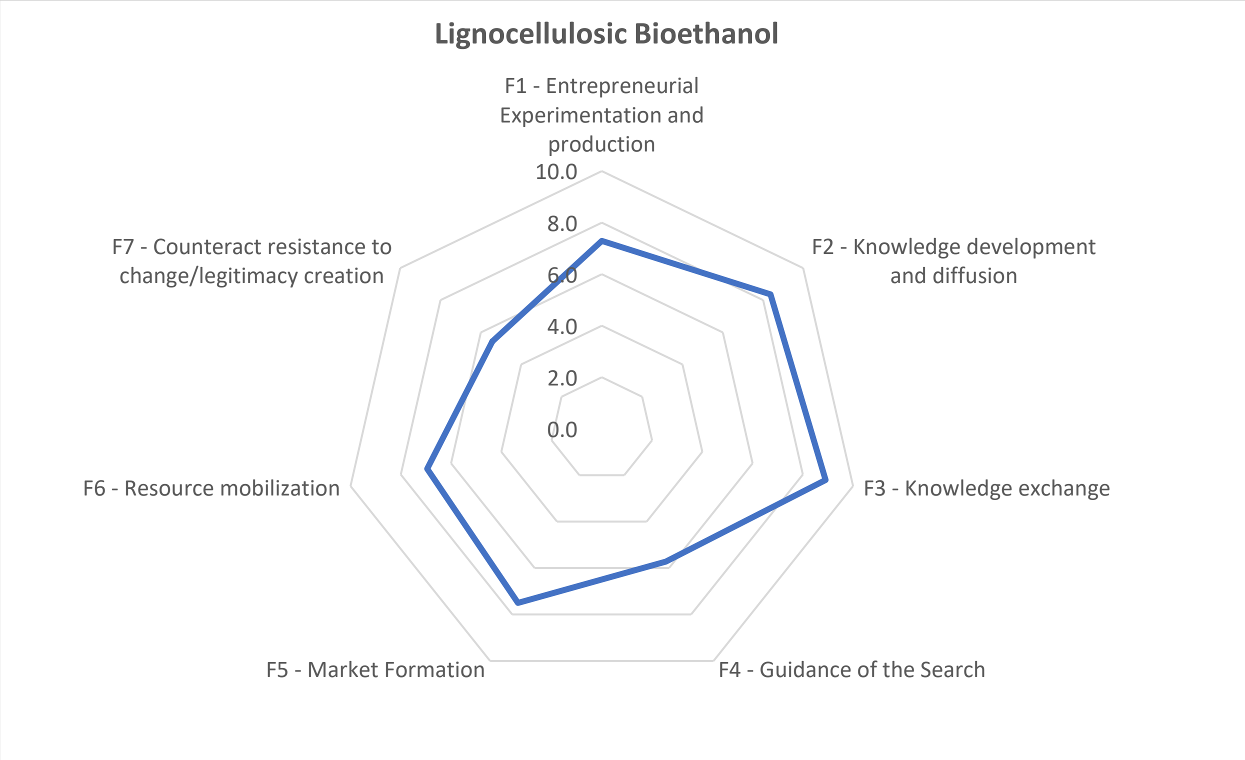

Figure 15. "Perennial crops for bioethanol" spider-graph

The analysis carried out showed that case study "Perennial crops for bioethanol" is relatively well developed with regards to functions Knowledge exchange (F3), which is above 9/10, Knowledge development and diffusion (F2), and Counteract resistance to change/legitimacy creation (F7).
The technology turned out to be quite well developed, with a remarkable quality and quantity of knowledge development within the value chain and sufficiency of pilot trails, with a very good accessibility to studies carried out. Moreover, there is a considerable frequency of concerns and workshops related to this case study, along with an extremely high availability of skilled human resources. In addition, the size of the existing market in regards of this case study is already relevant, and there is a favourable public acceptance of the energy crops and biofuels related to this case study.
However, also in this case some limitations have been found in terms of Guidance of the Search (F4), whose average score turned out to be below 6/10. Besides, it turned out that there are no strong Governmental policies in support of the TIS development, nor policies on substrate usage regulation. Moreover, the access to financing options should be better managed to achieve a complete establishment of case study "Perennial crops for bioethanol".

3 Conclusions

After the Technology Innovation System assessment was concluded for each single case study, a comparison of the four have been performed. As a first step, the four spider graphs were overlapped as visible in **Figure 16**.

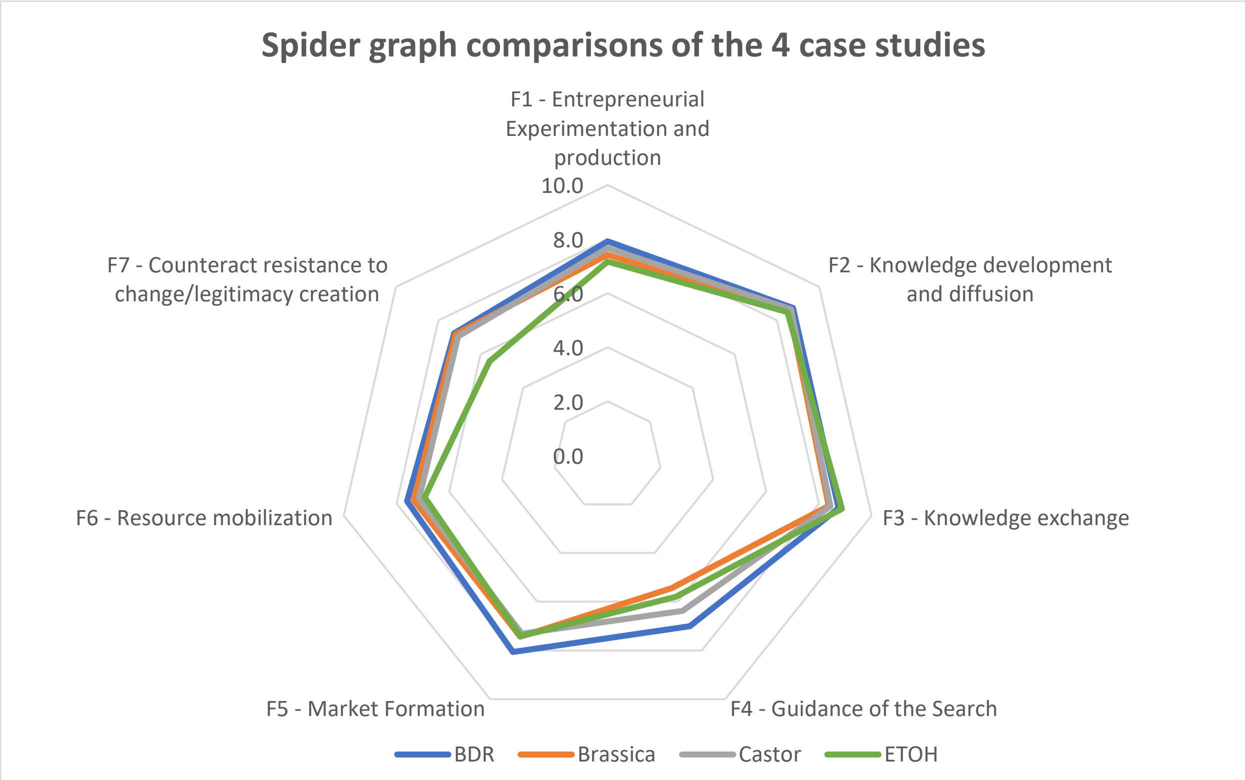

Figure 16. Comparison of TIS results of four BIKE case studies

As also reported in the assessment of each case study, the most relevant weaknesses of the technology innovation system for all Low ILUC biofuels production routes is represented by the **Guidance of the Search**. This function is the most critical for all case studies. On the contrary, Knowledge development and diffusion, as well as knowledge exchange appear to be strong functions for all.

Figure 16 shows that, as also anticipated by the phase of development trajectories, the TIS of lignocellulosic ethanol production from perennial crops presents more critical aspects. In particular, the Function 7, on counteract resistance to change, and legitimacy, is not sufficient for ensuring the future development of this low ILUC biofuel. Also, the resource mobilization could be improved compared to other case studies.

On the other side, Biogas Done Right presents a promising Technology Innovation System, with no specific weaknesses. Even if no biomethane to liquid plants are still operating in Europe, a relevant barrier has not been identified in the present framework. This because the biomethane value chain is already in place and that Biogas Done Right model developed in Italy demonstrates to be sustainable and easily doable at different scales. The deployment of biomethane to liquid refineries, not yet in place at large scale in the past years, could be now unlocked by a favourable economic condition.

The two case studies concerning HVO production from castor oil and brassica oil are similar, with the main difference in Function 4: Guidance of the search. In particular, Castor oil cultivation in dry, arid land seems to be more accepted as sustainable Low ILUC practice, due to the fact that the produced, non-edible oil is cultivated in marginal lands, not usable for food. A different condition is identified for the cultivation of Brassica as a cover crops. In this specific case, Low ILUC certification should be ensured by cover cropping practices. The uncertainty about the certification and market direction doesn't make the case study of Brassica for HVO less promising. However, the technology innovation system for this specific case study requires an upgrade in terms of long term, clear policy measures at EU level. The need of a more structured, long term and clear policy framework, at national and EU level, represents one of the most relevant outputs of this study. Particular attention should be given to the development of national targets among member states, to respect the target proposed by the European Commission RED II directive. Another relevant bottleneck is represented by the lack of a specific engagement and support measures, at national level, to foster Low ILUC risk practices and, thus, the production and usage of low ILUC risk feedstock. The uncertainty about countries supporting measures delays the development of a clear market vision in the Low ILUC biofuels sector, but doesn't affect the interest of investors and market actors, which demonstrate to be aware about the potential of Low ILUC risk biofuels in the next EU energy mix. However, in all cases, with specific relevance for Lignocellulosic bioethanol, a relevant weakness stays in the resistance to change, in the difficulty of creating a feedstock value chain, as well as in the difficult legal procedures. Despite technology development and sustainability about using Low ILUC feedstock for bioethanol production has been demonstrated, lignocellulosic biomass is traditionally adopted for conventional purposes, for this reason, the technology innovation system related to this case study resulted to be less advanced than others. However, the energy crisis, the climate emergency, as well as the geopolitical context, combined with the EU targets reported in the RED II, could represent the starting point for the take-off of lignocellulosic bioethanol, as well as for the whole sustainable biofuels sector.

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