EIP-AGRI Focus Group
Sustainable industrial crops

FINAL REPORT
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1. Executive summary

Industrial crops can be defined as crops that provide raw materials for processing into non-food products. Industrial crops can have many benefits including carbon sequestration, displacement of fossil fuels, improving profit margins for farmers and enhancing utilisation of marginal and contaminated land. They can also help farmers in the transition to organic and sustainable farming as many crops work well with organic fertilisers using regenerative methods to care for soil. The use of industrial crops as sources of raw materials for traditionally petroleum-based products, like polymers and solvents, will facilitate a shift to more sustainable consumption of resources. The key question of this Focus Group is **how industrial crops can contribute to new market opportunities, business models and sustainable farming systems, which create value for farmers in the EU, while not replacing food production**.

The Focus Group brought together experts in the area of industrial crops including researchers, farmers, advisers and industry professionals. Although the benefits and immense potential of industrial crops are very apparent, there are a number of challenges for the sector to overcome before these crops are integrated into established farming practice. The lack of confidence and experience in growing industrial crops is perceived as a barrier for progression of the sector. More information and sharing of knowledge through building networks and encouraging cooperatives will help the sector to develop. Demonstration projects which can provide transparent business models for farmers and industry is a key aspect for the evolution of the sector.

The experts compiled five Minipapers to elaborate the current knowledge base in the sector and provide examples on value chains that future farmers/entrepreneurs can glean inspiration from. Areas highlighted include the potential environmental benefits industrial crops can offer, the valorisation of marginal or contaminated lands, examples of value chains such as hemp and miscanthus, all while avoiding competition with food crops.

Several areas requiring further research and development were identified. Some examples include Operational Groups focusing on developing cohesive networks to streamline the supply chain from field to customer ensuring farmers are achieving fair prices, development of demonstration value chains, further research on potentials of marginal and contaminated land for production of industrial crops and research on the life cycle assessment of crops.

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2. Introduction

Industrial crops offer new market opportunities to European farmers and support the development of a bio-based economy in the EU. These crops are defined as crops providing raw material for industrial processing into non-food products. Farmers growing industrial crops can be key actors in producing high added-value products such as bioplastics, bio-lubricants, biochemicals, pharmaceuticals, bio-composites and bioenergy. In doing so, they can improve their revenue. Entering these new value-chains often requires significant changes in agricultural business models, new investments and the interaction with new economic actors. Access to knowledge and innovation, expert advice and cooperation are essential elements for success, especially for small- and medium-sized farms.

As a replacement of petroleum-based materials, plant-based materials can contribute to achieving climate and energy targets. However, there is a concern that industrial crops may replace food production, especially if they are grown on fertile land. In marginal lands, on contaminated soils or through multi/intercropping this risk is less acute. Sustainable production of industrial crops may even help territorial regeneration and potentially provide diverse ecosystems services, like improving soil organic matter and structure as well as biodiversity. Against this background, this EIP-AGRI Focus Group gathered existing knowledge and relevant practical experience and good practices in farming industrial crops on different types of agricultural land in Europe without replacing food production.

The Focus Group brought experts from all over Europe together (see **Annex 1** for details) to address the following tasks:

- **Collect practical and inspiring examples and good practices in growing industrial crops** in Europe while not replacing food production.
- **Identify existing value chains of bio-based materials where farmers have the potential to play a substantial role**, through long-term agreements or direct participation, while considering different bio-climatic conditions, agro-ecosystems and forms of cooperation along the chain.
- Discuss **strengths and weaknesses of the identified value chains**, notably with regard to the diversification of farmers' incomes and the environmental performance of the holding and of the whole value chain.
- **Suggest innovative business models** to foster integrated links between production/business/applied research.
- Identify further research needs from practice and possible gaps in technical knowledge.
- Suggest innovative solutions and provide ideas for EIP-AGRI Operational Groups and other innovative projects.

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3. Brief description of the process

The selected members of the group (Annex 4) met several times online due to Covid – 19 travel restrictions. The group of experts came from a range of backgrounds such as farmers, advisers, researchers, industry and NGO representatives.

A starting paper written by the Co-ordinating Expert and feedback from the group through a questionnaire directed the first meeting. The starting paper highlighted the main considerations around sustainable uptake of industrial crops and highlighted the potentials to utilise marginal and contaminated lands to produce crops for processing. It detailed the potential crops that could be grown and their associated markets. The paper also highlighted a number of considerations for crops around efficiencies in their growth and how to ensure farmers are achieving the highest return on their investments.

During the first meeting, several experts presented their experiences in both farming and processing industrial crops. These practical presentations led to an interactive discussion focussing on barriers and opportunities for sustainable industrial crops in Europe.

The group identified the following topics as key areas to focus on for further discussion:

- Crops on Different Soils (Marginal/Contaminated etc.)
- Rotational Crops/Cover Crops/Crop Rotation/Intercropping
- Seeds/Breeds/Standards/Licensing etc.
- Market Opportunities/Value Chains (Logistics/High Value End Uses/ Employment/Co-operation)
- Environmental/Sustainability/Climate Change (CO_2 abatement/Biodiversity/Healthy Soils/Standards/LCA)
- Paper on Full Value Chain Cycles of Crops (including Rural Development/Territorial aspects)
- New High Potential Crops
- Multi-Purpose Crops (by-products from food/crops that feed both food market and industrial market)
- Knowledge Exchange and Training (Advisory/Education/IT/Machinery etc.)

At the conclusion of the first meeting, the experts prioritised and streamlined these key topics into five Minipapers outlined below (complete list and details in Annex 5):

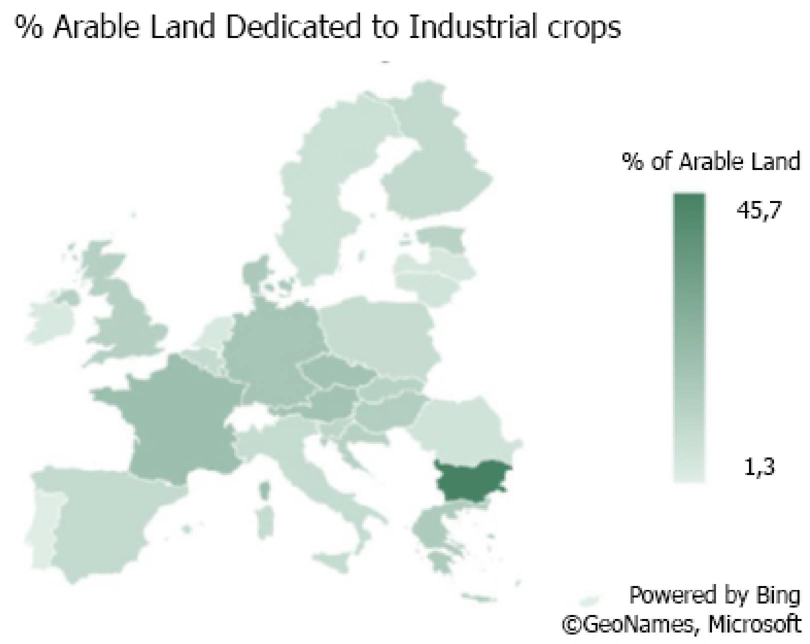
- Environmental/Sustainability of Industrial Crops (Minipaper 1).
- Selected Value Chains on Industrial Crops (Minipaper 2).
- Market Opportunities for Multi-Purpose Crops in the EU: a promise of growth, jobs and sustainability in rural areas (Minipaper 3).
- Industrial Crops for Marginal and Contaminated Lands/ Intermediate Crops and Intercropping Strategies (Minipaper 4).
- Review of Industrial Crops as part of Advisory, Research and Educational Programmes in Europe (Minipaper 5).

In the second half of 2020, the experts finalised the draft mini-papers, identified ideas for EIP-AGRI Operational Groups as well as needs for further research based on practice needs.

4. State of play

4.1 Framing key issues

The area of land covered by industrial crops in Europe, at the last census in 2016, was 4.7% with Bulgaria having the highest percentage of arable land dedicated to industrial crops [1] (Map 1 below). There are a number of factors that contribute to the low uptake of industrial crops throughout Europe. Some of these factors include a lack of a necessary market, an apprehension around adopting new agronomy practices required for new crops and land costs. Concerns regarding potential food vs non-food conflicts can also contribute to a low uptake in an area.



Map 1. Percentage of arable land dedicated to industrial crops in Europe according to the decennial Agricultural Census published by Eurostat in 2016.

Industrial crops have the potential to supply sustainable raw materials to several industries and replace petrochemical based materials in the market. Rapeseed and sunflower are the most plentiful industrial crops available to supply alternative markets like biofuels and bioproducts, but their agronomy requirements mean they directly compete with food producing land. A method of utilising marginal and contaminated land while supplying a sustainable industry is a key objective of a number of stakeholders in this sector (**Minipaper 4**). A sustainable business model where farmers are achieving good returns from new crops on underutilised land and diversifying incomes is a key necessity for the sustainable growth of this area in Europe.

[1] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_lac_indus&lang=en

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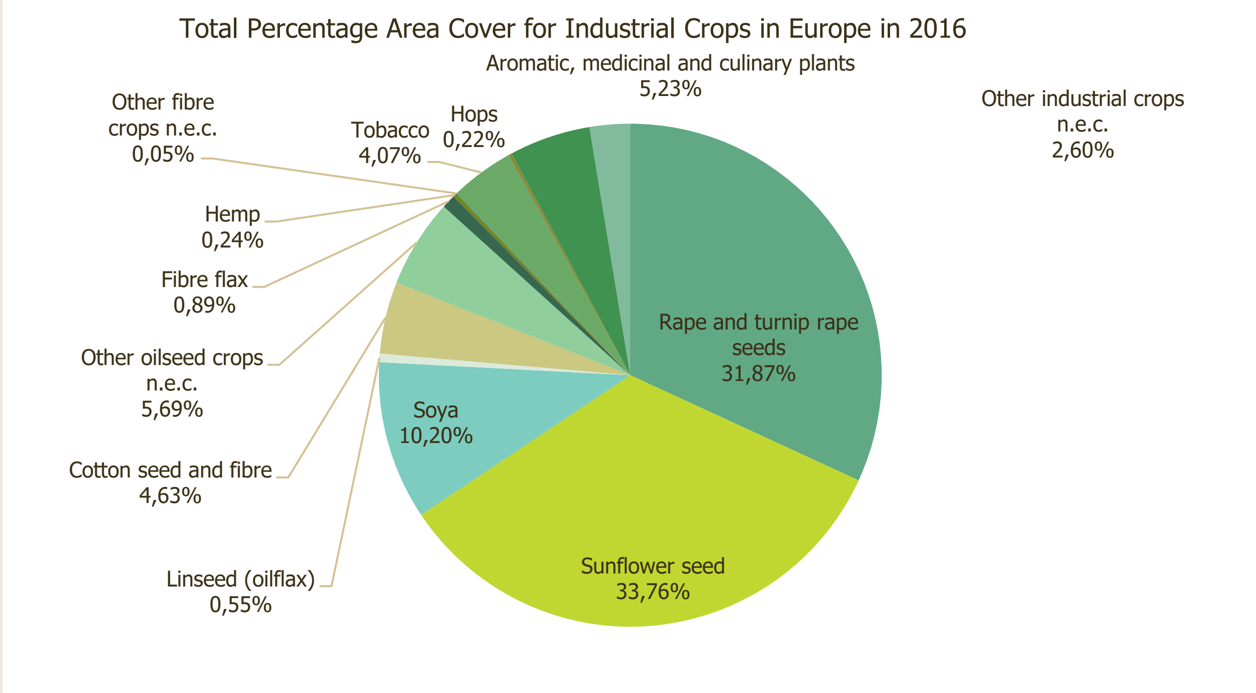

Figure 1. Breakdown of industrial crops by percentage area covered in 2016[2]

The bio-based circular economy is an important focus area for the European Union to help reduce reliance on CO_2 intensive activities and materials and ensure a more localised economy can sustainably develop from this transition. The bio-based economy is in a relatively early stage of development and requires extensive planning to ensure it will achieve objectives like sustainable markets and non-conflict with food etc. for all stakeholders involved.

Potential uses for industrial crops were identified by the Focus Group with high potential for developing a bio-based circular economy. Fibres were identified as having the biggest potential market due to their flexibility of use in a number of industries including building materials, textiles and paper production. A key consideration here is that industrial crops, in many cases, not only have a number of market potentials from individual crops, but also have a positive environmental impact due to their biodegradable nature and ability to replace petroleum-based products.

The broad range of uses for industrial crops can add a certain durability and insurance for farmers during crop price fluctuations and is a key aspect to be considered. The experts identified better prices for industrial crops and greater flexibility in harvested crop usability as the main risks for industrial crops to displace food production (see **Annex 2**, Fig 1b.).

[2] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_lac_indus&lang=en

5. Market opportunities for Industrial Crops

A key consideration for the sustainable uptake of industrial crops is the presence of a strong business model and market. The experts compiled an inventory table of the potential market opportunities for industrial crops and highlighted their benefits, considering social, economic and environmental aspects (**Annex 3**). The group voted on the six most promising business avenues for industrial crops from the original inventory outlined in **Annex 3**:

- Hemp for pharmaceuticals / supplement / cosmetics
- Aromatic plants for pharmaceutical / cosmetic / food additives
- Ligno-cellulosic biomass crops (switch grass / willow / miscanthus / poplar)
- Hay/ Miscanthus for paper production. Hemp fiber for textile and paper.
- Fibre crops for construction materials (hemp / flax / kenaf)
- Willow and poplar for land reclamation (marginal and contaminated lands)

The discussed market opportunities satisfied a number of criteria regarding positive economic, social and environmental aspects. The threats to these market opportunities were also identified and considered when identifying the research needs and the needs for EIP-AGRI Operational Groups.

5.1. Good practices

A perceived lack of knowledge and experience regarding agronomy of industrial crops and their markets has meant that uptake throughout Europe has traditionally been low. Therefore, a key objective for the focus group was to identify and share good business models that can either be replicated or used as inspiration for farmers looking to diversify their farming practices:

Industrial crops services provided to biodiversity

Industrial crops have the potential to offer a multitude of benefits including enhancing habitats and increasing biodiversity by reducing the effect of habitat fragmentation which can be a result of conventional crop production. Growing crops such as willow, hemp, camelina, aromatic plants and miscanthus requires less soil tillage, thus causing less habitat disturbance, compared to most regular arable farming. They also tend to need less herbicides and pesticides. In addition, crops like hemp have a complementary flowering season that ensures there is a supply of pollen when there is a scarcity from other crops (see **Minipaper 1**); this is also a benefit of willow. The complexity of the canopy and diversity in a number of native industrial crops (cardoon, flax, lavender) also benefits wildlife, soil fauna and native avian species by increasing canopy cover, nesting areas and material, pollinating plants for insects and healthy soil interactions due to reduced agricultural interference.

Industrial crops resource efficiencies

Due to the nature of industrial crops, the resources required for each crop can be adapted to individual locations depending on local environmental conditions and suitability. Industrial crops with high transpiration rates like willow are more suited to humid climates while crops like hemp or cardoon, which have been reported to use significantly less water, may be suited to a drier climate (see **Minipaper 1**). Planting the correct industrial crop in the correct location can have immense beneficial consequences for water and resources needed to grow the crop. Drought tolerant industrial crops like camelina, cardoon, and castor bean will not need irrigation and can be grown in areas where land abandonment may be a risk (see **Minipaper 2**).

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Figure 2. View of castor bean at several stage of growth (emergence, early stages of growth and seeds ripening) (source: CRES; Greece)

Many industrial crops require fewer chemical inputs, like fertilisers and fuels, due to their agronomy. Perennial crops like willow, miscanthus, poplar, switchgrass etc. require fewer inputs annually due to their longer rotation and associated recirculation of nutrients through leaf fall. This results in an improved environmental profile for some perennial industrial crops like willow. The reduction in emission intensive activities like annual ploughing, fertiliser application and herbicide use ensure efficiency.

Industrial crops on marginal land

Industrial crops like miscanthus, willow or hemp have immense potential to utilise land that may be considered too unproductive for food or that has elevated levels of harmful compounds or elements (either contaminated or naturally occurring). A great deal of work has been completed by a number of projects to date (**Annex 1**) to map the potential land area that could be utilised for industrial crops and has assigned suitable crops to each area. The ongoing MAGIC (Marginal Lands for Growing Industrial Crops) project is identifying suitable land that has the potential to grow a number of industrial crops e.g. camelina, poplar/willow, sweet sorghum, lavender etc. while not displacing food production. The MAGIC project has highlighted that there is approximately 29% of European land that is underutilised and has potential to sustain industrial crops. While the PANACEA (Path of Non-food Agricultural Crops into European Agriculture) project is compiling and disseminating existing knowledge in the area for distribution to farmers.

Several industrial crops like miscanthus, willow, camelina etc. yield reasonably well on less fertile soils. While the crops may still need inputs like fertiliser to sustain yields, there is immense potential to achieve yields from marginal lands especially if high value end uses can be identified for all fractions of the crops.

- An example of marginal land being reassigned for industrial crops production occurred in Guadalajara in Spain where the dry, arid soils could not sustain sufficient yields of tillage crops and the land was subsequently abandoned. Lavender was trialled on the land and yielded well, achieving a good return on investment for farmers.
- *Cynara cardunculus* (Cardoon) is being grown on abandoned marginal land in Porto Torres in Sardinia, Italy. The nature of the crop means it can yield well on marginal and un-irrigated land ensuring a continuous supply of raw materials for the nearby bio processing facility. The crop is supplying the facility for the production of a number of biobased materials including bio plastics all within a local economy. Cardoon can also be used in the production of solid biofuel, seed oil, biodiesel, paper pulp, green forage, and pharmacologically active compounds.

The value that some industrial crops like poplar can provide to enhanced biodiversity on marginal lands has been documented widely. The use of marginal lands for monocultures of industrial crops may be considered a risk to some biodiversity but approaches like hedge maintenance and biodiversity bridges throughout may mitigate negative effects.

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Industrial crops on contaminated land

Soils can be contaminated from a number of sources including mine waste, petrochemical leakage and naturally occurring high levels of heavy metals. These lands are typically left fallow as there is a risk of bioaccumulation of contaminants in food crops or the soil will simply not grow crops. A number of industrial crops, like miscanthus and willow, have been identified that not only grow on these contaminated sites but also can bioaccumulate compounds like heavy metals etc. hence removing them or stabilising them in soil (More details below Example 1 and Minipaper 4). While the harvested crop may have a certain concentration of these compound in their biomass, these can usually be either extracted or abated in the processing of industrial crops. In the case of miscanthus, inorganic compounds can be stabilised in the root system ensuring the above ground biomass is readily available for further processing.

Figure 3. Seed based Miscanthus hybrids grown on metal contaminated arable land in Bytom, Poland (MISCOMAR+, Institute for Ecology of Industrial Areas)

Certain varieties of crops like willow are also hyperaccumulators and can accumulate very high levels of compounds like nickel and copper which is an excellent method of phytomining metals for further uses. This aspect of industrial crops is another positive financial benefit to farmers in appropriate areas where high levels of metals are present in the soil.

Food and industrial crops growing together (Co Cropping/intercropping, intermediate cropping)

A key consideration for European agriculture development is the efficiency at which the finite land resource can be utilised. Industrial crops are in the early stages of developing innovations in how to grow food and raw materials in a symbiotic way. How crops can work in tandem benefiting yield and improved agronomic practices is increasingly recognised. There is potential for food crops and industrial crops to grow together rather than compete against each other.

Example: Miscomar/ Miscomar+

Research carried out in Poland found Miscanthus cultivation for industrial uses like anaerobic digestion or direct combustion for bioenergy can be safe and profitable on marginal and contaminated land.

More information in Minipaper 4

A number of traditional food crops need long rotations to ensure soil is not being eroded, depleted of nutrients or accumulating a pathogen load for subsequent crops. Certain industrial crops like lupins can help food growing soils by acting as a break crop that can improve nitrogen-fixing capabilities and add a different dynamic to soil structures. The use of industrial crops in this way not only offers a supply of raw materials to the non-food market on a rotational basis but also can help improve the yields and sustainability of subsequent food crop production.

A double cropping strategy is another approach to allow food and non-food crops to be grown together. Some crops like sorghum and sunflower can be grown with arable crops all in a relatively short growing cycle meaning the traditional fallow period for the land is producing additional income for farmers. Camelina also has been successfully used as an intermediate crop with a cultivation of 80 to 90 days (see **Minipaper 4**). The use of industrial crops, like camelina with organic production of legumes, has resulted in a number of benefits being achieved particularly good soil coverage, reduction in chemical inputs, higher returns for landowners on the same area of land etc. (see **Minipaper 4**).

Figure 4. Cotton and wheat relay intercropping (Zhang, 2007)

Another approach, agroforestry, can be used to grow both food crops and industrial crops like poplar and willow. The agro-forestry approach has been proven to improve soil moisture retention, aid soil structure, wind break capabilities, provide diverse habitats for mammals and avifauna and has the potential to create buffer zones to benefit and protect water quality (see **Minipaper 4**). Examples of agroforestry include growing food crops like wheat, sunflower etc with lines of poplars or willow distributed approximately every 30 m throughout the field and along ditches for interruption of hydrological connectivity.

The use of agroforestry methods like growing willow or poplar on headlands has the potential to utilise the entire field and help with soil structure and buffer zones. Growing industrial crops in combination with food crops in this method has symbiotic benefits with regards to soil structure, biodiversity, environmental services and a diversified income potential for farmers.

Multiple end uses, one crop

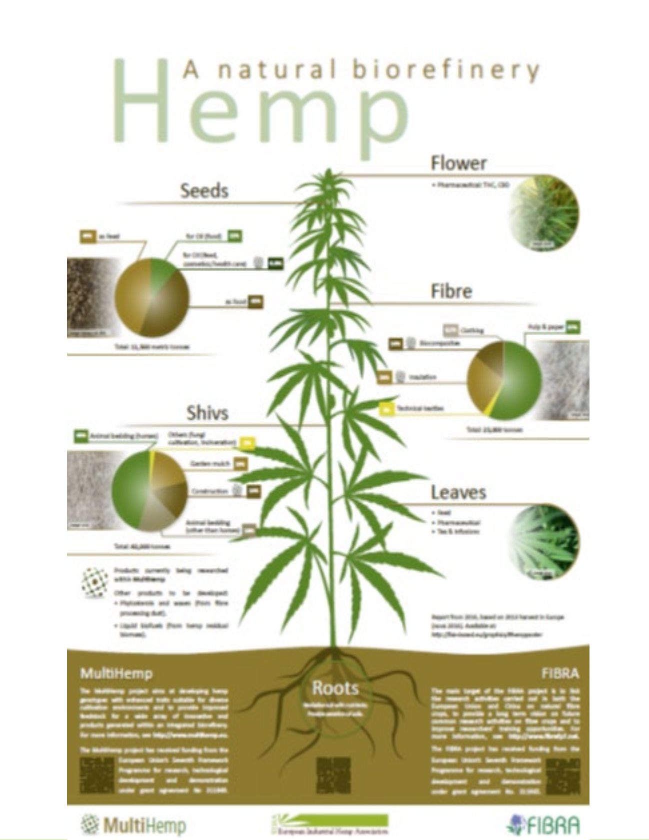

Figure 5. Industrial Hemp- a natural biorefinery. (Poster developed by EU projects Multihemp & FIBRA)

It is increasingly important to reduce waste and use all parts of crops. Numerous crops can satisfy both a food-based market and an industrial market and thus reduce crop waste. Crops like camelina and oilseed crops can be used for a number of end uses like biofuels, bio based products etc. Crops like hemp can be used for oil extraction while the other fractions can be used in paper pulp production, textile production and construction materials (Figure 2) (see [Minipaper 3]). Concurrently, woody crops have multiple end uses like wood industry feedstock, paper and pulp production, bioenergy feedstock etc. Crops like poplar and willow are very efficient at providing raw materials for a biobased economy in a relatively short rotation (2-10 years) in contrast to traditional forestry rotations (30-40 years) (see [Minipaper 3]).

5.2. Success and fail factors for uptake of Industrial Crops in Europe

A key factor for European farmers to successfully take up growing of industrial crops is their economic and environmental sustainability. Farmers and processors need a clear vision and strategy on how they can set up and sustain alternative enterprises. This will be achieved by developing business models that highlight both the success factors and the threats to the industry like lack of cooperation between stakeholders, lack of production/processing knowledge etc. The summarised success and fail factors from the collaborative work are outlined as follows:

Success factors for industrial crops

There is a large, growing market for raw materials sourced from industrial crops due to their greener profiles. Biobased products are inherently easier to market and an upsurge in the use of biobased and biodegradable materials in recent times has increased the potential market share. Industrial crops are a key component of a fully circular biobased economy where materials are locally sourced, recycled and sustainable throughout their life cycle. The food vs. fuel debate has instilled a conscious approach in most stakeholders to ensure industrial crops do not compete with food producing land.

Life Cycle Assessments (LCA) of biobased circular economies have highlighted that carbon emitted from processing activities (harvest to transport to production) is cycled back through the growth of the crops and the entire process can be considered significantly less carbon intensive than fossil fuel-based supply chains[3] (see **Minipaper 1**). Industrial crops have potentials to be the foundations of local, sustainable economies by ensuring sourcing of raw materials from local farmers, creating employment, and moving away from expensive petro-chemical based products.

Some industrial crops, such as lavender, camelina etc. have a higher tolerance to stress factors and can therefore grow on less favourable soil types (see **Minipaper 3**). Utilising marginal soils can add additional revenue streams for farmers. They also have potential to remediate some soils and ultimately allow them to be returned to food production. Industrial crops like camelina (see **Minipaper 4**) can also enhance the nutrient cycling efficiencies of some soils, improving soil structure and helping reduce fungicide loads when used as a break crop in tillage rotations.

A number of infrastructural systems can be easily adapted by farmers to grow and harvest some industrial crops, reducing the capital cost of integrating alternative crops into already existing systems. Machinery used for harvesting forage crops can also be used (with adapted header) in the harvest of willow, poplar and miscanthus crops. Drying floors typically used for grain drying can also be used for drying the above-mentioned industrial crops. In central and Northwest of Europe the schedule of harvest for arable crops (early autumn) or forage crops (early summer) and willow crops (late winter/early spring every 2/3 years) can complement each other ensuring there is no conflict in use of on farm infrastructure.

The potentials to utilise the entire crop have also been highlighted, especially in **Minipaper 3**. Ensuring a market for each component of industrial crops ensures a better return on investment for farmers and processers, reduces waste and mobilises a greater proportion of sustainable products.

There is excellent potential to develop good training infrastructures around the development and education of farmers/landowners on growing and producing industrial crops. Farmers are inherent entrepreneurs but the new avenues for industrial crops may present opportunities for farmers to become involved in a greater scope of the value chain. The development of these markets has the potential to bring together sustainable cooperatives that are dynamic and can return excellent revenues to their shareholders (farmers) and local communities. Excellent relationships and networks are important for the success of the industry.

Fail factors for industrial crops

Lack of knowledge regarding the entire process chain may result in apprehension for extensive uptake of industrial crops. There is a well-established body of research and knowledge surrounding the agronomy and markets for traditional crops, which may limit initial uptake of alternative crops. A number of potential markets for industrial crops are underdeveloped and may not be developed until sufficient raw materials can be sourced resulting in a chicken and egg scenario.

Some crops like willow require expensive initial capital costs. Farmers may not be willing to take them up to diversify their production until a proven profitable market can be ensured. There is high risk in the area for pioneers in both growing and processing crops; the farmer and processer are dependent on each other. Good management of the entire system is paramount to its success. A broad skill base is required to ensure the entire value chain is coherent and beneficial to all members. The danger of individual processes turning into silos reduces the benefits of the circular economy aspects.

Competitive natures in the industry may hamper the progress of the sector if a cooperative approach is not undertaken by all stakeholders. Sharing experience and knowledge is a key success factor for the development of the industry and all stakeholders need to ensure commitment to sharing of success and fail factors. EIP-AGRI Operational Groups are an excellent way to overcome the restriction of knowledge sharing by fostering the exchange of information and a cooperative environment.

3 **https://circulareconomy.europa.eu/platform/sites/default/files/the_circular_economy_and_the_bioeconomy_-_partners_in_sustainabilitythal18009enn.pdf**

6. What can we do? Recommendations

6.1. Ideas for Operational Groups

EIP-AGRI Operational Groups (OGs) are financed under the Rural Development Programmes and bring together farmers, researchers, advisers, environmental groups, agri-businesses and NGOs to identify innovative solutions to particular challenges facing the agri-food sector and rural economy. At present, the number of OGs dealing with industrial crops is limited[4]. The Focus Group experts have identified a number of areas where Operational Groups could greatly benefit the development of the sector. These include but are not limited to:

- Bridging the gap between the farmer's production of industrial crops and consumers through improved supply and value chains. This group would focus on how farmer associations/cooperatives could help relationships between farmers and industry. A unified organisation could streamline the onerous work associated with traceability, networking, database management, research and development, regulations, intellectual property management and distribution etc.
- MAPCROP – an Operational Group on selected MAPs (medicinal and aromatic plants) genetic material to enhance industrial production of high-quality raw material:
    - develop breeding programmes based on wild plant populations with interesting and relevant characteristics,
    - develop agronomic techniques and machinery to adapt cultivation of some wild species improving extracts production,
    - identify opportunities for intercropping MAPs adapted to local conditions.
- Operational Group dedicated to specific industrial crops such as hemp fibres and other natural fibres with the objective to achieve high quality, low environmental impact value chains. Create a national hub (case study) for harvesting and processing of crops like organic hemp to demonstrate efficient technology in organic farming to other interested parties.
- Operational Group demonstrating the possibilities of utilising contaminated sites for industrial crop production. Explore the potential of redefining those land areas as "non-food Industrial crop land" for on-going bioresource production. Different opportunities will exist in different EU member states. Different levels of pollution and different crops for site phyto-management. Demonstrate site stabilisation and pollution immobilisation.
- Use marginal land for biomass crop (poplar, willow) establishment and apply circular economy models to use nutrient rich waste (wastewater treatment sludge, biomass ashes, biogas digestate) to increase the yields on marginal lands to make farming on marginal lands economically sustainable.
- Utilising and measuring industrial crops, such as poplar, willow etc., as carbon capture and storage vehicles. Operational Groups could bring together farmers, processers, researchers and finance experts on carbon accounting, biodiversity services/ecosystem services quantifying the value of the services these crops can provide in the fight against climate change and the environmental services they can provide.

[4] https://ec.europa.eu/eip/agriculture/en/eip-agri-operational-groups-%E2%80%93-basic-principles

6.2. Dissemination Recommendations

- Develop coordinating biomass trade centres. Biomass trade centres can act as a central location to store, market and sell energy crops allowing improved efficiencies due to economies of scale and a consistent supply to end users. They could also act as hubs to deliver upskilling and advisory services to their community while identifying knowledge gaps for further research.
- Disseminate information and demonstrate the adoption of new industrial crops in regions where there is a lack of technical knowledge and market development. These groups would focus on building networks between key stakeholders (farmers, agronomists/advisers, processers, researchers) to ensure information can be distributed and avoid repetition of inefficiencies.

6.3. Research and innovation needs from practice

The following paragraphs outline a compilation of areas that need further information to promote innovative, productive, and sustainable industrial crops and markets. Each suggestion is detailed under a general theme.

General

1. An improved network for farmers, processers, advisers, research bodies is a challenge for the sector. Focus Group 40 has helped to begin addressing this area, but further work is required. Several further suggestions from the experts in the Focus Group are:
    - Framework for better cooperation between all parties.
    - Track & Trace (Origins, short supply chains, local value adding, etc.).
    - Networking, Database, IP-Transfer.
    - Research & Development Support.
    - Farmers associations/cooperatives (potentially incentivised on an increasing scale), better involvement of consumers on the benefits of the end products, policies, municipalities, processing units, distributors, investors, legislators, researchers.

2. Demonstration models and research development of entire crop utilisation for numerous markets. An example of two crops that could be used and the issues which need addressing are outlined below:
    - Multipurpose hemp use (whole plant approach) as a real-existing example demonstrating the expansion of the area. Issues which need to be addressed through research/practice include:
        i. Shortening supply chains.
        ii. Supporting local sourcing.
        iii. Supporting investments for business start-ups for example fibre processing, first processing and textile (technical + clothing) processing (yarn spinning, etc.)
        iv. Developing fibre processing facilities.
        v. Developing modern technology (industrial scale).
        vi. Identifying seed varieties and varieties for fibre & seed.
        vii. Dealing with legal barriers re flower/leaves (flowering-/fruiting tops). Network, database IP-Transfer.
        viii. Involving, and gaining cooperation from policy makers, all industry stakeholders, investors etc.

    - Miscanthus has a range of applications, including its use in energy production, such as a filler material or reinforcement, within construction materials, pulp and paper manufacture. Other end-uses include high value equine bedding and sustainable composite materials for markets such as the production of biodegradable plastics and fibres for car parts. The principal constraints to growing miscanthus for a number of end uses are common and can be summarised as.
        i. volatility of produce value due to market fluctuations,
        ii. volatility of produce value due to variable quality and
        iii. the absence of large-scale processing facilities and guaranteed purchase schemes for growers in some areas.

3. Scaling up of bio-based industry needs including trialling large scale crops (1000-2000 ha) can reveal numerous issues that may be missed on smaller research scales. The scaling up of these research plots will identify issues and mitigation measures needed to successfully integrate industrial crops into current practises. Issues like land mobilisation, political and local community considerations, biodiversity impacts (negative and positive) can be identified to roll out of crops.

Environmental

1. Phyto management potential of industrial crops under field test demonstrations would be a very worthy research undertaking to further demonstrate the services that industrial crops can provide to the environment and eco systems. Field trials on a greater variety of contaminated soils would build an excellent repository of information for a wide range of soils across Europe.
2. Specific research on the impact of industrial crops on biodiversity. How can industrial crops be planted and managed in such a way to enhance biodiversity further? Research needs to ensure the agronomy recommendations for industrial crops is cognisant of enhancing biodiversity.
3. Life cycle assessment of industrial crops like hemp etc. to ensure full confidence in reported figures. Collect data to be able count the CO_2 footprint of production of crops like hemp, miscanthus and willow for industrial materials from start to finished products. Life cycle cost analysis would also be very beneficial research to demonstrate the feasibility of industrial crops from both an environmental prospective and a financial one.
4. Research is needed to be able to validate the carbon captured by industrial crops. Although some groups are already working in this area a concerted effort to network and ensure good collaboration to ensure a number of crops are accounted for is required. Carbon sequestration and storage has to be evaluated while growing industrial crops using different technologies and rotations. Farmers and landowners need practical mechanisms to benefit from carbon tools. Carbon counting and potential credits could be an economic motivation to grow industrial crops if quantified correctly.

Agronomy

1. Research is needed on how to measure and improve profits of industrial crops on marginal land. Analysis on feasibility of lower yielding, organic crops on marginal land and break-even costs. Whole plant approach needed (double and triple use) and identification of high value end use to compensate lower yields. Quantify needs for external subsidies to initiate market. Research on business models including use of different varieties, propagation methods, technologies, use of nutrient rich waste etc.
2. Research on the flora of contaminated sites that can be used as a genetic pool for breeding of industrial crops. Identification and cataloguing of current flora or indicator species that thrive on contaminated sites may aid with breeding programmes and choosing the correct crop for the soil.
3. Increase land availability for industrial crops without displacing food crops through research into intercropping/catch cropping.
    a. Develop innovative and sustainable growing schemes that can also provide ecosystem services like:
        i. Catch cropping
        ii. Relay cropping
        iii. Intercropping
    b. Developments and optimisation of the growing schemes can come from:
        i. Mechanisation
        ii. Crops` growth cycle (precocity) of main and catch crop
        iii. Agronomics, including species rotation/association etc.
4. Evaluation of already existing research on industrial crops to find out where the gaps are which need to be filled. Work on new opportunities - with necessary adaptations (varieties, agronomics / disease tolerances, training needs etc.) largely focused on other EU countries.
5. Further research is needed on breeding programmes of industrial crops, agricultural technologies, introduction of new crops. Ensuring the correct plant is recommended for the correct climate and soil. Breeding programmes for industrial crops adapted to local conditions at EU level. Initial resources are required to sufficiently improve yields to attract farmer interest as well as industry (cooperatives, seed companies)

6. Better agronomic knowledge on the cultivation of aromatic crops and oil crops. Breeding programme from wild plant populations. Research on best practices regarding agronomy of the crops. Develop guidelines for interested farmers.

Harvesting/Processing

1. More knowledge on sustainable options to extract, recover, added value compounds and on the processing to high value products. Use of essential oils, extracts, oils by the chemical industry to substitute fossil derived products need better research to ensure sustainable substitution is achieved.
2. Innovation, research & development of harvesting and processing machinery is needed. Development of harvesting technologies for medium (5-8years) rotations of crops like poplar or willow is one area of particular interest. No harvesting machinery specifically for MAP crops (rosemary, sage, thyme) currently available. New prototypes researched to identify suitable machinery to efficiently harvest MAP crops. Development of a database of machinery available and suitability for each crop, climate, budget, scale etc would be very beneficial to farmers and the industry to ensure entrepreneurs/farmers have full sight of costs and limitations in harvesting and processing their crops.
3. Research on characteristics and quality of biomass grown on marginal and contaminated soils would ensure the suitability of industrial crops for different markets would be identified early on in development of business proposals. Research on how to 'clean' crops before processing may also mobilise a greater proportion of raw materials from contaminated land. Possibilities to produce clean energy from a contaminated biomass and to recover the metal if it has a high value. Improve technological gaps around purification/extraction of contaminants (high value phyto-mining).
4. Greater knowledge is required on how biomass with different characteristics can be used in one processing plant. Research on methods to ensure processing machinery can be developed to be adaptable to a number of feedstocks. Further research on methods of pre-treatment for industrial crops to ensure high efficiencies in the processing of crops.
5. More research on the processing options and on how biopolymers characteristics can be improved to move TRL (technology readiness level) to 7-8. Cellulose, from industrial crops, conversion to biopolymers is very topical at the moment, with a significant move away from fossil fuel-based polymers apparent. Research on efficient ways of supplying polymers from industrial crops needs greater research.
6. Further research on the incorporation of industrial crops into bio composites needed and highlighted. Although extensive research has been carried out on the numerous uses for industrial crops this area has not been exhausted yet. There is immense potential to find new areas that industrial crops can supply. Also, publishing the benefits industrial crops can bring to materials is important e.g., incorporating miscanthus fibres into bio composites improves the impact performance of the polymer.
7. Research on how to develop Biomass Trade Centres to mobilise the sector efficiently and in cooperation. These centres could reassure industry of the supply and quality of biobased raw materials.
8. Research on drying methods of biomass needs to be brought to farmers. Much of this work has already been researched in the past. Grower guidelines of energy crops need to be continuously updated with the best available information for agricultural research and advisory networks. Farmers like structures such as market outlets, machinery and infrastructure.

Markets

1. Biobased material end-of-life management is an important area of focus for sustainable development of the sector. Researching ways to ensure the final products are easily recyclable or biodegradable will be important to ensure the sustainability of the sector.
2. Specific research on European cotton access to the market. Participatory research with farmers for the adoption of organic farming by ensuring there is access to the market. Identification of the best approach to engage and develop partnerships between locally grown organic cotton and the European textile industry. Creating partnerships along the European organic cotton supply chain to add value for farmers and processers. Develop research and demonstration farms to exhibit best practices to achieve acceptable yields.

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Regulatory

1. Sustainable standards for cultivation and manufacturing of industrial crops. Overview of existing sustainable standards, networking with the groups who currently work on similar standards and ensuring standards include a wide spectrum of sustainability criteria for industrial crops. Ensuring regulations are applicable and representative of actual on farm experiences.
2. Assessing and suggesting realignment of regulatory barriers to uptake of industrial crops. Identification of areas of conflict, contradiction and overlap to ensure elimination of barriers for progression of the sector.
3. Assessment of the role industrial crops can play in carbon farming schemes and inclusion of those in the schemes being developed across the EU.

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Annex 1 – European Projects on Industrial Crops (Non exhaustive list of relevant projects supported by the EU)

Acronym	Title	Period	An. spp.
	Industrial crops		
	MAGIC - Marginal lands for Growing Industrial Crops: Turning a burden into an opportunity (RUR-07-2016 - Resource-efficient and profitable industrial crops on marginal land)	07/2017 – 06/2021	727698 RIA
	Diverfarming - Crop diversification and low-input farming across Europe: from practitioners engagement and ecosystems services to increased revenues and chain organisation (RUR-07-2016 - Resource-efficient and profitable industrial crops on marginal land)	05/2017 – 04/2022	728003 RIA
GRACE	GRACE - GRowing Advanced industrial Crops on marginal lands for biorEfineries (BBI-2016-D02 - Improvement and adaptation of industrial crop varieties and novel sources of biomass to diversify biomass feedstock for biorefineries)	06/2017 – 05/2025	745012 RIA
DiverIMPACTS	DiverIMPACTS - Diversification through Rotation, Intercropping, Multiple cropping, Promoted with Actors and value-Chains Towards Sustainability (RUR-06-2016 - Crop diversification systems for the delivery of food, feed, industrial products and ecosystems services - from farm benefits to value-chain organisation)	06/2017 – 05/2022	727698 BBI-IA-DEMO

Acronym	Title	Period	An. spp.
	FP7		
FP7 OPTIMISC	OPTIMISC - Optimizing Miscanthus Biomass Production	2007-2013	289159
MultiHemp	MultiHemp – Multipurpose hemp fo industrial bioproducts and biomass	09/2012 - 02/2017	311849
Crops 2 Industry	Crops2industry - Non-Food Crops-to-Industry schemes in EU27 (RUR-07-2016 - Resource-efficient and profitable industrial crops on marginal land)	09/2012 - 02/2017	227299

Acronym	Title	Period	An. spp.
Oil crops (crambe, camelina, castor, safflower, rapeseed, sunflower, tobacco, etc.)			
	COSMOS - Camelina & crambe Oil crops as Sources for Medium-chain Oils for Specialty oleochemicals (ISIB-05-2014 - Renewable oil crops as a source of bio-based products)	03/2015 – 08/2019	635405 RIA
	FIRST2RUN - Flagship demonstration of an integrated biorefinery for dry crops sustainable exploitation towards biobased materials production (H2020-EU.3.2.6. - Bio-based Industries Joint Technology Initiative (BBI-JTI)	07/2015 – 06/2019	669029 BBI-IA-FLAG
Acronym	**Title**	**Period**	**An. spp.**
Lignocellulosic crops (perennial crops/grasses, fiber crops, woody species)			
	BECOOL - Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels (LCE-22-2016 - International Cooperation with Brazil on advanced lignocellulosic biofuels)	06/2017 – 05/2022	744821 RIA
Acronym	**Title**	**Period**	**An. spp.**
Carbohydrate crops (sweet sorghum, sugarbeet, corn, cassava, potato, etc.)			
	PULP2VALUE - Processing Underutilised Low value sugar beet Pulp into VALUE added products (Bio-based Industries Joint Technology Initiative)	07/2015 – 06/2019	669029 BBI-IA-DEMO
	CORNposite - Valorisation of corn processing by-products into plastic bio-composites (SFS-08-2015-1 - Resource-efficient eco-innovative food production and processing)	03/2016 – 07/2019	717829 SME
	AgroCycle - Sustainable techno-economic solutions for the agricultural value chain (WASTE-7-2015 - Ensuring sustainable use of agricultural waste, co-products and by-products)	06/2016 – 05/2019	690142 RIA
	NOAW - innovative approaches to turn agricultural waste into ecological and economic assets (WASTE-7-2015 - Ensuring sustainable use of agricultural waste, co-products and by-products)	10/2016 – 09/2020	688338 RIA

Annex 2 - Questionnaire Feedback from Focus Group 40 (75% response rate)

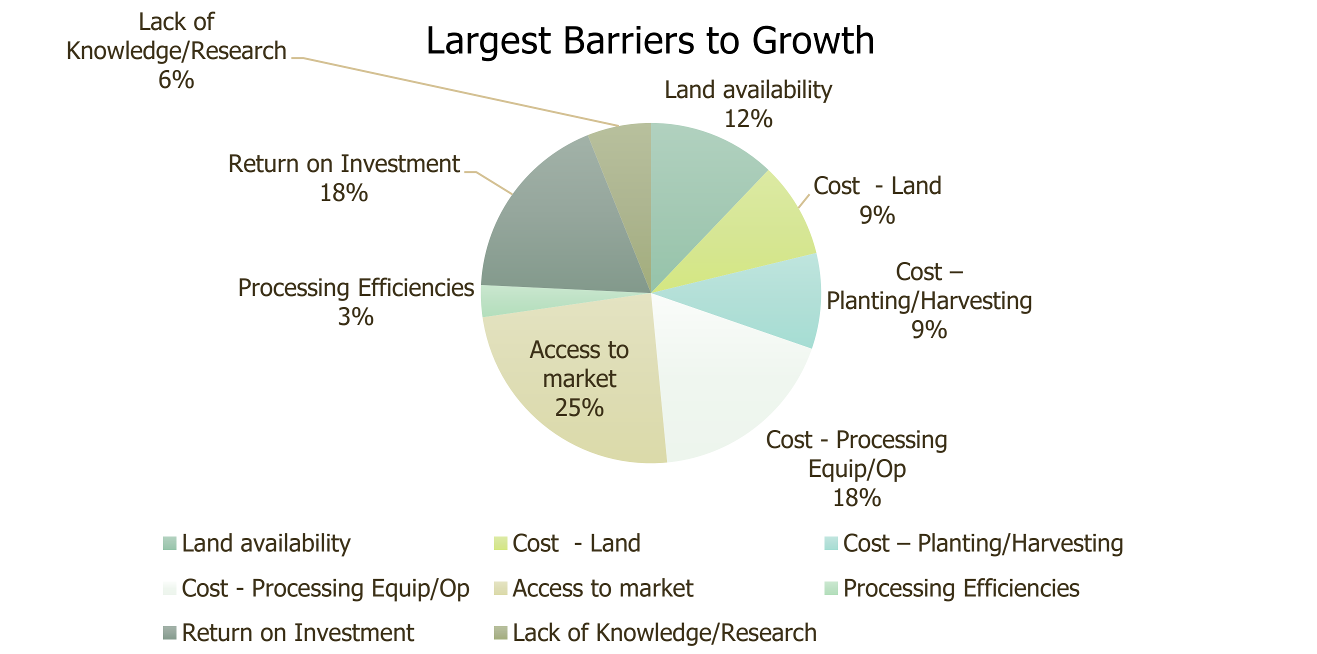

Fig. 1a. The focus group experts were asked to identify the largest barriers they felt were inhibiting the uptake of industrial crops in Europe at the minute (75% response rate from experts).

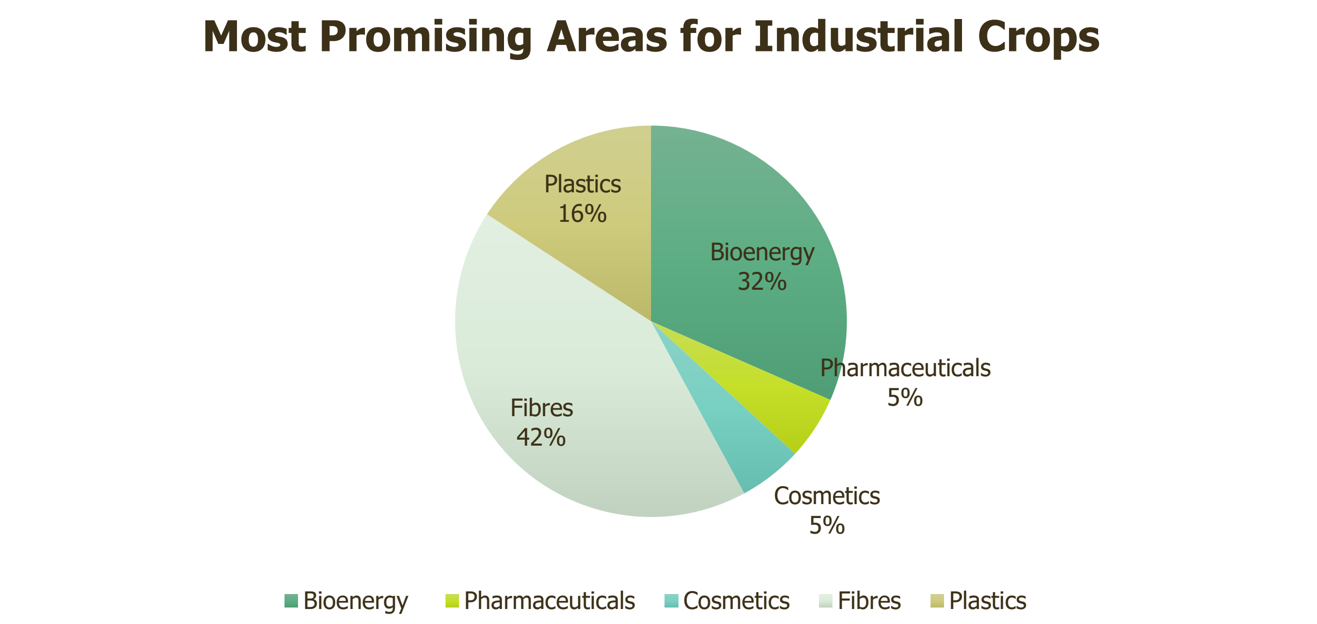

Fig 1b. The experts were asked to rank what the most likely end use for industrial crops could be. 42% of respondents ranked using industrial crops as raw materials for fibre production as the main use for crops (75% response rate from experts).

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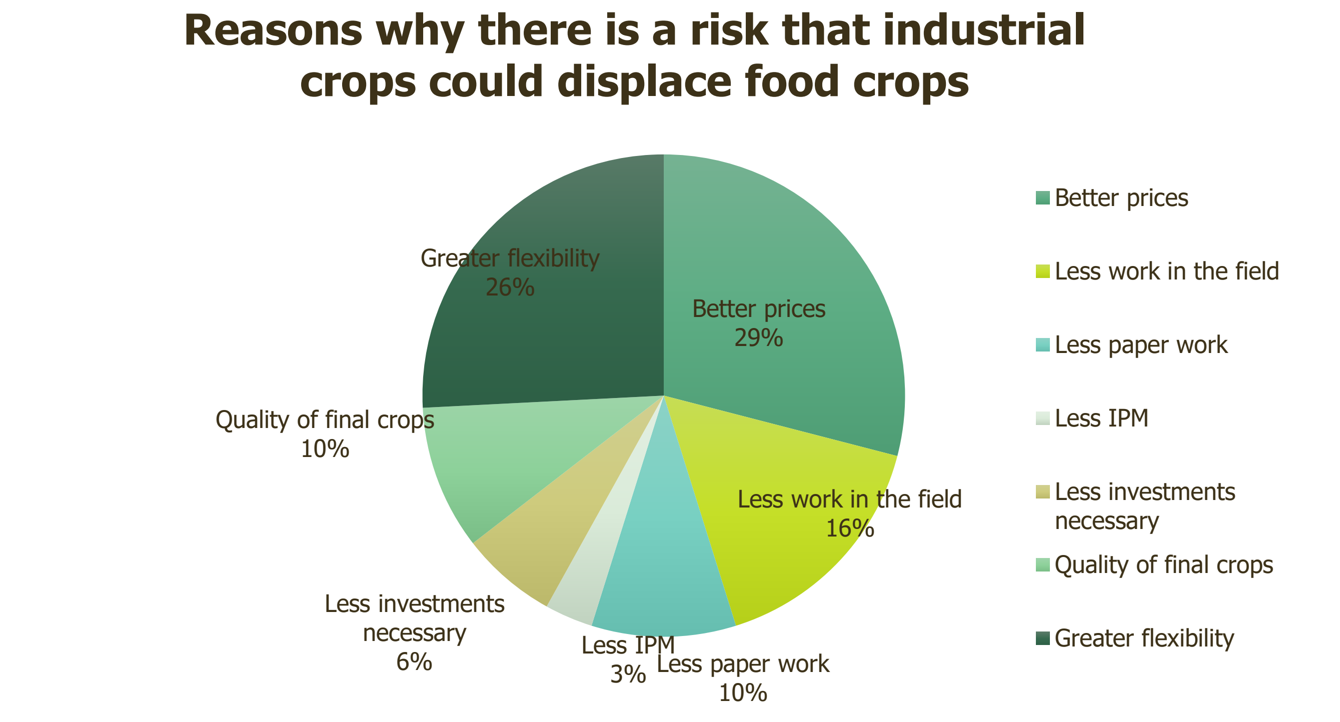

Fig 1c. The experts were asked to identify the top reason that industrial crops may replace food production. The threat of better prices for industrial crops was most identified as a reason for food displacement with greater flexibility around harvesting times identified as the second greatest threat (75% response rate from experts).

Annex 3 – Summary of Inventory Table (Potential market opportunities for selected industrial crops (working table compiled by FG experts during their first meeting))

Name of the crop + used for .... (a) bioenergy (b) pharmaceutical extract (c) fibres/paper (d) plastics (e) building material (f) recovery of meta (g) land reclamation (h) other potentials	Description incl. "what"? (good practice, market opportunity, business model, farming system) incl. "where"? (at farming level, at processing level, ...+ country)	Economic aspects	Social aspects	Environmental aspects (soil, air, water, biodiversity,...)	Comments / additional info
Willow used for bioenergy	Farmers grow willow to sell for combustion in boilers in Ireland, Poland, the UK and Sweden etc. Willow can grow on marginal lands and has many other benefits for farmers. Willow has a very high calorific value for combustion by processers and can displace many fossil fuels like peat and coal.	Rural employment +++ Lack of commercial infrastructure --- Guaranteed market --- Any diversification could improve economics +++ Heat & electricity system (centralised or decentralised) +++ 1 ha willow = 5000 litres of kerosene (10.5 kWh/l)	Barrier crop (eg Rural employment +++ France separation of city/farms). +++ General aesthetic improvements +++ Noise barriers. +++ Food v fuel --- Willow beetles --	Flood prevention. +++ Heat (& power) distribution system +++ Wastewater management. Biodiversity (CAP-EFA) +++ RED (heat targets) +++ Livestock agricultural sustainability improvements (GHG abatement, Water quality, NH3 emissions) +++ Can be grown on a wide range of sites.++ Phytoremediation /sustainability / soil contaminant bio & phytoaccumulation (Cd, Zn) and stabilisation +++	In some EU countries willow would be considered forestry (eg Greece.) this is not the case in N.European countries where SRC is agriculture. Willow & miscanthus establishment support exists in France. Excellent multifunctional crop with current clear uses.
	Short Rotation Crops (SRC) like willow can be used as second-generation biofuels	Unlimited market + High yields in good or fertilised (e.g. with nutrient rich waste) soils + High fluctuation in price (linked with oil price) -- Commodity market - high price dependency on import from outside EU markets - In different regions of Europe no grants - High establishments crop investments-subsidies needed -Cascading use improves profitability +	Opportunity for income diversification for farmers + Additional employment during off-season (winter) at farms +	Can be grown on marginal land with the help of nutrient rich waste enrichment + Less inputs + Irrigation needed in southern Europe - Improves SOM, C sequestration in wood, especially growing in longer (15-20 year) rotations + Landscape, biodiversity benefits + Preserves leaching of nutrients, no/little herbicide usage + Preserves usage of traditional forest biomass +	

		Diversification of income + Need for special breeds (scientific knowledge) in different climatic conditions – Need for special harvesting equipment in some circumstances and infrastructure for biofuel production is costly -High transportation costs (needs to be used locally) -			
Willow use for land reclamation	Willow can be used to bring contaminated land back to production and generate income for farmers from fallow land.	Restoring ex-mine sites ensuring income from land + Can help some poorer soils improvement/ organic additions which may not have generated any income previously +	Demonstrate the use of sites that were considered a burden to society as beneficial +	Willow can bioaccumulate some compounds, removing them from the soil +	
Willow use for waste management.	Willow can be used to polish wastewater treatment outputs. Farmers can use on their land.	Farmers can benefit as this will help fertilise the crop and reduce costs of purchasing fertiliser + Some countries pay farmers to take the waste providing another revenue stream ++	Waste is being used on a non-food crop +	Willow crops have very high growth rates utilising the waste quickly reducing risk of leeching + Reduces the use of artificial fertilisers + Some issues in some countries around the classification of the outputs as waste as opposed to fertiliser -	
Willow and eucalyptus use for pharmaceuticals and cosmetics.	Compounds can be extracted from willow bark to use in pharmaceutical compounds and or cosmetics. Salicylic acid currently being extracted in a number of European countries (Holland, Germany and Ireland) for use in cosmetics and medicines. Compounds extracted from the eucalyptus leaves can be used for pharmaceuticals and cosmetics, etc	High value end use for crops, margins in pharmaceuticals are high + Excellent market for naturally sourced compounds for pharma sector + High cost to extract the useful compounds – Other revenue streams for remaining parts of the crops +	Provide local employment +	Crops can provide environmental services as they grow + Natural sourcing of ingredients for medicines +	"nweurope/projects/project-search/biowill/ Salicins Miyabeacinn Anti-cancers
Willow use as lignan and lignocellulose feedstock.	Willow can be processed into a number of materials, inner biomass can be separated and used as a raw material in pulp production or bio materials.	Diverse revenue stream for growers ensuring security of market for crop + Can be further developed into high value second generation biofuels + Costs of processing equipment high for initial investments -	Easy to market as displacing fossil fuels +	Can be processed into biopolymers displacing fossil fuel derived plastics +	
Willow used as flood abatement.	Willow can be used as a buffer crop near watercourses to reduce risk of nutrient run off. Willow can also be used to absorb excess	Can be grown in buffer zones that cannot be used for other crops + Can bring less productive, flood prone land back to profitability +	Can be a key player in improving farmers social standing around water quality +	Reduces potential run off and eutrophication of water bodies + Can stabilise banks and reduce silting of rivers +	

	water in land because of its high transpiration rates.			May be difficulties harvesting crops near watercourses -	
Hemp used for fibre/paper.	Hemp fibre and cellulose can be used for textile and paper production. Long and short fibre can be blended with cotton, flax or used in pure form. Cellulose can also be used for non-woven textile and paper production. The first transformation needs to be done close to or even on the field itself (retting, breaking, scutching). Mobile scutching machines could help reducing costs and reaching regions without fixed scutching facilities.	Hemp needs very low inputs at farm level and can grow on marginal lands meaning enhanced income from poorer land for farmers + Lack of special machinery and infrastructure - Good market opportunities for organic seeds, CBD, automotive industry + Diversification of income + Cascading use improves profitability +	Hemp can be grown in all EU Member States meaning better cooperation throughout Europe and sharing of knowledge + Social stigmatisation - Employment in rural areas, skilled people +	Can be used in marginal land + Less need of pesticides and fertilisers + The root system, improves SOM, soil structure, erosion control, C sequestration + Crop in rotation + High water needs – Hemp paper production does not necessarily require toxic bleaching chemicals as it can be whitened with hydrogen peroxide +	Hemp fabric is naturally resistant to UV light, mould and mildew, and if treated, to salt-water. It also is a very breathable fabric and naturally comfortable."
Hemp for cosmetics.	Hemp seed oil can be processed as a primary compound in a number of cosmetics.	Cosmetics containing cannabis extract (both seeds and leaves) are sold at higher prices compared to other botanicals + Additional revenue for farmers + Legal confusion surrounding these products (refrains further investments) -	Cosmetics containing botanical (especially cannabis) are attracting many young and motivated entrepreneurs to a sustainable sector +	Production of extracts is more sustainable than the production of chemicals +	(-) All hemp derived raw materials need to be permitted as ingredients for cosmetics to develop market. On the basis of the fact that hemp is not a narcotic, the Cosmetics Ingredients Database should be changed accordingly. To be added: CANNABIDIOL - DERIVED FROM CANNABIS SATIVA LEAF EXTRACT"
Hemp for biodiversity and carbon farming	If used as alternative to carbon-based raw materials, hemp would allow us to spare phenomenal amount of CO_2. Hemp is also positive for biodiversity and particularly for the bees and pollinators population[3].	No current system to pay farmers for carbon capture – High marketing capabilities for any products because of carbon sequestration of crop and services to biodiversity+ Diversifies revenue stream for farmers (numerous potential markets for crop) +		Being grown with little or no synthetic phytosanitary products, hemp can be of help for enhancing biodiversity in rural areas. A study assessing 23 crops along 26 biodiversity parameters, identified both oilseed and fibre cannabis as superior to most major crops in terms of limiting damage to biodiversity+ Flowering cycle occurs usually between July and September, coinciding with a lack of pollen production from other farm crops. Being wind pollinated, dioecious and staminate plant, cannabis produces large amounts of pollen, a vital nutritional source for bees during period of floral scarcity ++	

				A study on the bee population in hemp fields, identified 23 different genera in northern Colorado (US) plantations, with a majority of Apis mellifera at 38%, followed by Melissodes bimaculata at 25% and Peponapis pruinosa at 16% +	
Hemp for bio pesticides	Hemp is high in terpenes > hemp-based biopesticides based on essential oils or other extracts produced by steam or CO_2 distillation. Farmers/processers would have a very high value market.	High value end market for pesticides + High capital costs to extract and process terpenes -	Promotes sustainable sourcing of bio chemicals +	Displaces traditional pesticides in a holistic manner +	
Hemp used in crop rotation.	Hemp can be used in crop rotations (break crop) with food crops. Farmers can give the land breaks with hemp between crops and in some cases can help yields increase.	Better revenues for farmers as hemp (break crop) can increase yield of following crops + Hemp crops can be sold instead of ploughed back in +			
Hemp use in bioplastic	Hemp is a valuable raw material for a variety of bio-based plastics, resins and bio-composites, it can be moulded in any shape and for any purpose. Most of these bioplastics are also biodegradable. Both fibre and cellulose are used, depending on the technique and the application. Nanocellulose for biomedical devices, paper electronics.	Excellent market for hemp derived plastics + Establishment of processing plants and equipment still expensive –	Increased use of bioplastics from hemp could improve rate of use of biodegradable plastics throughout society +	Because of its high growth and shading capacity hemp eliminates efficiently weeds leaving the soil in optimum conditions + Because of its resistance and natural capacity to suppress weeds, hemp is cultivated without or with very little need for chemical treatments most of the time + Displaces fossil fuel derived plastics +	Preliminary results from Rodale Institute (US) trial suggest that the presence of hemp as a summer crop and its earlier harvest date suppressed weeds season-long and provided a wider window for establishing the winter crop. This is considered to be another advantage of including hemp as a rotation crop.
miscanthus for paper production	few companies in Europe try to establish the installation to production the paper from miscanthus	(+) lower costs connected with paper production in comparison to paper form wood	(+) new jobs especially in energy transition regions in Europe	(+) it can be used in marginal lands (+) carbon sequestration	
Cotton for fibres and textiles	Organic cotton requires less inputs from farmers to grow like herbicides, pesticides etc.	Good market opportunities for organic cotton + CAP cotton specific payments (fix land, no food competition) + High grade of technology in cultivation and use of cotton already available +	Excellent potential for small farmers + Relatively high labour force required ensuring local employment +	High water needs - Food competition -	

Tobacco for use in pharmaceuticals	Tobacco is used in pharmaceutical industry as substrate for medicines	(+) new market opportunities for pharmaceutical and biopesticide use	(-) stigma of negative health impact (+) traditional cultivation for small farms in mountainous areas	(+) low requirements of water (-) food competition	
Miscanthus for bioenergy	Miscanthus yields well on marginal lands and gives a revenue from poorer land. Good examples in Poland of miscanthus planted on post-industrial lands that are not used for food production.	(+) high yields in good soils (+) diversification of income (+) cellulose and lignin products derived can add value to the crop bioenergy, building materials. (+) job creation. fibres for bedding materials. (+) expensive establishment (+) reasonable management costs (+) can be pyrolysed / gasified however these technologies are underutilised/developed (+) cash flow improvement due to annual harvest	(-) less labour force (+) opportunity to income diversification (+) employment in rural areas, skilled people (+) not as big a leap in practice change. A big grass!!	(+) it can be used in marginal land (+) less inputs (-) irrigation needs in southern Europe (+) improves SOM, structure, soil erosion, C sequestration, landscape, biodiversity (+) fossil fuel displacement / GHG reduction. (+) good for stabilisation and erosion protection but not an accumulator. Can grow on varied soil types and pH. (+/-) It can however displace other plants and their associated ecosystems	Its similar technology as per maize harvesting. Miscanthus fits well to alternate seasons to Maize or Grass.
Miscanthus for building materials and other products	Miscanthus has a high cellulose and lignan content and is a good raw material for building materials. Nanocellulose for biomedical devices, paper electronics. Miscanthus for pulp for paper.	(+) multiply uses so farmers will always have a market (+) market for alternative building materials is strong at the moment	(+) provides local employment (+) develops local economies	(+) lower GHG burden with miscanthus sourced building materials through sequestration etc (+) miscanthus derived building materials safer for environment than cement-based regards both construction and demolition	
Miscanthus as a pre-treatment for land and land reclamation.	In trials in Poland tillage crops were planted in land that had previously grown miscanthus. These crops needed less fertilisation as a result of the previous crop of miscanthus. The benefits of miscanthus in this system are that the crop can be harvested for industrial uses and the land has also been improved for future food crops. Using the two alternating crops on rotation will help yields of food and industrial crops and increase revenues for farmers.	(+) improves the profit for land for farmers of both miscanthus and following food crops, also land that would be left fallow can grow miscanthus and provide a yield (+) cheaper method to utilise land than traditional extraction and treatment methods, provides a revenue stream for potentially abandoned land	(+) provides better returns for farmers on land and may help provide jobs locally	(+) Utilising fallow land and sequestering carbon	
Aromatic plants (*Artemisia absinthium*, *Thymus vulgaris*, lavandin, *Satureja*	Areas of Spain where deer have decimated tillage crops previously are now being used for production	(+) big market opportunities in the organic sector and essential oils (+) market opportunities for biochemical	(+) income diversification	(+) potential impact on pest control (+) very good in marginal lands and on	

montana) for medicinal, cosmetic and food packaging industry.	of aromatic plants as the deer will not eat certain varieties of these crops. Farmers can now comfortably use this land without worrying about crop damage.	(medicinal, biopesticides, etc) (+) on farm transformation potential (e.g. drying)	(+)employment generation	intercropping systems (+) low requirements of water	
Lavender/lavindin for aromatic oils.	Trials in South Spain are looking at intercropping food crops like olives and almonds with lavender crops. Excellent potential for land to be used for both food and industry in a symbiotic way. A large area of lavandin is growing and producing materials for aromatic processing on land that was deemed too arid for cereals production. Farmers can use land more efficiently.	Two markets for land + Able to obtain revenue from dry land + Good market +	Land can become a viable option for farmers to work locally +	Greater number of crops on land means greater diversity + Slows desertification if drier lands can grow crops +	
Aromatic plants (*Artemisia absinthium, Thymus vulgaris*, lavandin, *Satureja montana*) for medicinal and cosmetic industry.		Farmers can extract the essential oils (tax / diversification / value add +++ aromatic plants for traditional uses +++ biocontrol / biostimulants for chemical substitution – livestock +++ More technology required for extraction -- Extraction at cooler temperatures to preserve the aromatics / natural aspects of the oils -- Contract templates needed for industrial crop production. Contracted primary production. +/- seed/genetic supply. Issues on full control leading to monopoly. innovation required --- Machinery circles / cooperatives + machinery costs reducing	can be farm scale or industrial scale ++ Confidence to change to new crops. Inexperience in new crops. Securely financed contract growing --- Based on what quantitative? Qualitative?	Improved biodiversity ++ breeding / genetic improvement ++ support of bees / honey ++ pollinators ++	Large market – essential oils (agri-products so farmers can extract) pharma, cosmetics, Global market around Euro 5Billion. Growing industry. Chemical & cosmetic industry getting more interested. More competitive essential oil production in warmer climates.
Cardoon used on contaminated land.	Cardoon is tolerant to Cadmium in soil and can be grown for industrial uses on land that would otherwise be left fallow meaning improved revenues for farmers from fallow land.	Multiply markets, pharma, biodiesel, fibre, bioplastic (from extracted oil) + Can provide a revenue from less fertile land +	Excellent example of local farmers and industry working together to produce bio plastics in Italy ++	Bioaccumulate Cd. + Hard crop to remove -	Food and industrial crop. Leaves can be eaten/food. This would apply to many of the industrial crop developments – Integrated value chain essential for development of new crop uptake. Revenue / Risk adjustment.

					Cardoon example in Greece is similar to the Miscanthus example in Ireland
Camelina used for cosmetics.	Good models in Spain where the crop is grown on dry soils that cannot sustain food crops increasing revenues for farmers. Cameilina oil can be used in a range of cosmetic products and offers a high revenue end use for processers.	(+) cascading use improves profitability (+) diversification of income) (-) certified seeds (+) excellent market opportunities	(+) opportunity for income diversification (+) employment in rural areas, skilled people	(+) it can be used in marginal land (+) improves landscape, biodiversity (+) crop in rotation, cover crop	
Camelina can be used as a primary oil input for bio jet fuel and biodiesel.	Camelina can be processed for oil extraction that can be processed into biofuels. There is a big market for more sustainable liquid fuels that camelina can satisfy. There are good market opportunities for renewable transport fuels.				

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Annex 4 – List of members of the Focus Group

Name of the expert	Professional background	Country
Alexopoulou Efthymia	Adviser	Greece
Bagnara Gian Luca	Farmer	Italy
Caslin Barry	Adviser	Ireland
Ciasnocha Mateusz	Farmer	Poland
De Porras Miguel	Researcher	Belgium
Fernando Ana Luisa	Researcher	Portugal
Gabrielova Hanka	Farmer	Czech Republic
Herreras Yambanis Yuri	Industry	Spain
Johnston Christopher	Researcher	United Kingdom
Kruse Daniel	Industry	Germany
Mitsopoulos Anastasios	Adviser	Greece
Navarro-Rocha Juliana	Researcher	Spain
Papazoglou Eleni G.	Researcher	Greece
Pari Luigi	Researcher	Italy
Pogrzeba Marta	Researcher	Poland
Rabeau Sophie	Other	France
Šilininkas Mindaugas	Other	Lithuania
Tilvikiene Vita	Researcher	Lithuania

Facilitation team	
Donnelly Isabella	Coordinating expert
Gätje Emilie	Task manager
Kivistik Agnes	Co-task manager
Fernandez Lopez Susana	Backup
Onega Lopez Quico	Backup

You can contact Focus Group members through the online EIP-AGRI Network.
Only registered users can access this area. If you already have an account, you can log in here
If you want to become part of the EIP-AGRI Network, please register to the website through this link

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Annex 5 – List of Minipapers

No.	Title	FG members contributing
MP1	Understanding the sustainability aspects of Industrial Crops	**Mateusz Ciasnocha**, Ana Luísa Fernando, Hanka Gabrielová, Juliana Navarro Rocha, Mindaugas Šilininkas, Vita Tilvikiene
MP2	Selected Value Chains on Industrial Crops	**Efthymia Alexopoulou**, Mindaugas Šilininkas, Juliana Navarro Rocha, Yuri Herreras, Miguel de Porras
MP3	Market opportunities for multi-purpose crops in the EU: a promise of growth, jobs and sustainability in rural areas.	**Daniel Kruse,** Gian Luca Bagnara, Miguel De Porras, Ana Luísa Fernando, Hanka Gabrielová, Robin Meijer, Juliana Navarro-Rocha, Luigi Pari, Sophie Rabeau, Mindaugas Šilininkas.
MP4	Industrial crops for marginal and contaminated lands and for intermediate crops and intercropping strategies	**Eleni G. Papazoglou**, Marta Pogrzeba, Chris Johnston, Vita Tilvikiene, Efi Alexopoulou, Yuri Herreras Yambanis, Mindaugas Šilininkas, Ana Luísa Fernando.
MP5	Review of Industrial Crops as Part of Advisory, Research and Educational Programmes in Europe	**Barry Caslin**, Miguel De Porras, Hanka Gabrielová, Chris Johnston, Tasos Mitsopoulos, Luigi Pari.

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EIP-AGRI Focus Group Sustainable industrial crops

MINI PAPER 1: Understanding the sustainability aspects of Industrial Crops

JANUARY 2021

Authors

Mateusz Ciasnocha (Coordinator), Ana Luísa Fernando, Hanka Gabrielová, Sophie Rabeau, Juliana Navarro Rocha, Mindaugas Šilininkas, Vita Tilvikiene

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1. Introduction

Agriculture in the European Union is at the brink of what can turn out to be a tremendous opportunity or a tremendous challenge. The EU's ambition to become the world's first climate neutral continent by 2050 is being implemented across the board with its New Green Deal and the Farm to Fork Strategy in the agricultural sector. Farmers are already voicing concerns that high environmental standards, as well as the move to organic production and mandating lower use of chemical inputs, are too demanding.

Considering the growing demand for bioenergy and other plant-based industrial products it is expected that the production of industrial crops will increase in the next decades (OECD/ FAO 2017). This can cause a competition for land with food systems. However, this competition will depend significantly on crop type, mode of production, environmental context and future use scenarios (Ahlgren and Di Lucia, 2014; Dislich et al., 2017; Hertel et al., 2013; Gasparatos et al., 2018), Apart from strong effects on the national economy, the production of industrial crops can have substantial local effects on livelihoods and food security (Mudombi et al., 2016).

For industrial crops, the major environmental impacts are due to changes in land use as the result of biomass crop production; biodiversity impacts; water availability; soil changes and landscape impacts, including impacts on archaeological sites (ADAS, 2006).

In this reality of what can end up being a historical opportunity, or a tremendous challenge, EIP-AGRI Focus Group 40 – Sustainable Industrial Crops, has gathered to do all the information, so that it becomes the former: a unique opportunity for agriculture in the EU to transition towards providing even more ecosystem services than ever before. This includes aiming for emissions neutrality and possibly even for negative emissions in the future. The present Focus Group's s focused specifically on sustainable industrial crops in Europe: new market opportunities and business models which do not replace food production.

Focus Group's understanding is that in – say – 50 years' time the agricultural sector in the EU will be fully emissions regulated. So, if you are a farmer and you are a net emitter of greenhouse gases (GHG), you have to pay for what you are emitting. In certain other sectors of agriculture, like dairy, you may have an allowance of emissions within which you will have to arrive. If you emit more, you have to pay. If less, you can get extra revenue from carbon credits into your operation. If such scenario would be true right now, most of the European farms would be out of business. This is the scenario we have to prevent from happening.

The objectives of this Mini Paper are to provide insights into the environmental benefits that can be provided by industrial crops together with providing real-life case studies from the field on the topic, namely hemp and poplar.

2. Dimensions of Sustainability

Figure 1. Sustainability: Triple Bottom Line and Responsible Capitalism (Keith Murray, 2019)

Today, sustainability is no longer linked solely to the management of individual natural resources. The term has also become a synonym for sound and acceptable economic, social, and ecological development of society.

Sustainable agriculture is the management and utilization of the agricultural ecosystem in a way that maintains its biological diversity, productivity, regeneration capacity, vitality and ability to function, so that it can fulfil – today and in the future – significant ecological, economic, and social functions at the local, national, and global level, and that does not harm other ecosystems.

Currently, most of the energy and materials supply is based on fossil resources, which are finite, non-renewable and its use raises serious environmental concerns. Searching for more sustainable (environmentally, economically and socio-economically) alternative energy and bioproducts resources, more sustainable is considered an important global issue to prevent energy shortage, climate change, soil degradation and non-renewable materials depletion. Biomass represents an environmentally sustainable source of energy and materials, since it is compatible with the existing systems and presents a renewable and biodegradable character which is locally produced. Yet, the increasing demand for biomass raises the competition for agricultural land, accentuating the fuel versus food dilemma, and the land use change debate (Fernando et al., 2018a). Furthermore, to meet the biomass procurement, environmental sustainability can be questioned due to the intensiveness of the cultivation and the increased pressure on natural resources. Many industrial crops have been recognized as low-input crops and the high yielded biomass can be used for the sustainable production of energy, bioproducts, biomaterials or even highly protein feed/food or phytomedicine (in case of hemp). This work will present how industrial crops can be sustainable.

3. Soil

Common cropping management activities and crop traits affect soil quality through the nutrient status, organic matter (SOM), structural and acidic standings and erosion potentials. Assessing the impact of industrial crops on soil organic matter content, structure and pH is highly dependent on local conditions. Nonetheless, there are generic trends documented in literature that allow a comparison between short rotation forests, perennial grasses and annual crops. Annual cropping systems are the most damaging in terms of SOM content and structure due to high soil revolving, short permanence and litter removal. Crops presenting deep roots (hemp, sweet sorghum and sunflower) or if litter is left in the field, minimize the impact. Contrarily, the impact is enhanced when the harvesting process removes a portion of the soil (e.g. sugar beet). Woody crops and herbaceous perennials are reported to accumulate higher SOM and structural enhancement than annuals, due to the continuous permanence in the soil, high inputs of residues and vigorous root development. Also, most of the industrial crops are low input crops (in terms of fertilizers, pesticides) and therefore a less intensive soil amendment is in place, contributing to minimize impacts and to lower pH variations from the native status of the soil.

Perennial herbaceous and trees, by comparison with annuals, are even less impactful due to their lower input needs. Yet, regarding soil pH, some woody crops, such as eucalyptus, but not all increase soil acidity, something not verified in herbaceous crops and annual crops (Fernando et al., 2010). Concerning the erodibility, herbaceous perennials and trees exhibit lower potential due to the greater surface coverage over a long period of time, the continuous presence of an underground biomass and the greater interception of rainfall. Contrasting, annual crops show a higher erodibility potential, in particular crops that cover the soil over reduced periods of time, such as, sweet sorghum and sunflower. Some oil crops (e.g. Ethiopian mustard in the Mediterranean) show an impact similar to that of perennials when serving as a winter crop, as its permanence in the soil is longer.

Nutrient (N, P and K) surplus/deficit can be estimated by the difference between input (fertilizers) and output (emissions and crop uptake), and impact reduction strategies are limited to crop management options. Data collected in Europe on the cultivation of a range of industrial crops indicate that most of the crops showed a balanced profile in terms of phosphorus application. In terms of K and N, results indicate a deficit. This is not problematic for K, once the soils reserves are sufficient, but for N, this can contribute to soil depletion. However, nutrient deficits can be balanced by leaving on the field the crops residues, like sunflower stalks. (Fernando et al., 2010)

3.1 Benefits of Industrial Crops for Soils

Hemp is fast-growing crop which has a high leaf turnover rate and if grown in ideal conditions, fully cover the ground three weeks post-germination. The dense leaves rapidly form a natural soil cover material that reduces water loss and soil erosion. In addition, fallen leaves provide vital nutrition for the soil. If intended for fibre, hemp stalks are an important nutritive organic matter for the soil during retting (decomposition of the outer layer of the stalk allowing fibres to be accessible for manufacturing). Because of its height and shading capacity, hemp efficiently eliminates weeds leaving the soil in optimum condition. Preliminary results from Rodale Institute (US) trial suggest that the presence of hemp as a summer crop and its earlier harvest date suppressed weeds season-long and provided a wider window for establishing the winter crop. This is considered to be another major advantage of including hemp as a rotation crop. Finally, hemp can also be used with great efficiency in land reclamation. Indeed, it is considered as an optimal pioneer crop, notably because of its phytoremediation capacity, meaning the ability to remove heavy metals from the ground. It is a cadmium-tolerant plant and is resistant to long term exposure to heavy metals. More on the remediation capacity of hemp can be read in the other mini papers produced by the EIP-AGRI working groups.

The European Commission has repeatedly declared the intention to avoid the cultivation of non-food, and especially energy crops in fertile agricultural land, in order to avoid the consequential effects in the food market (EC 2009, EC/JRC 2013). Therefore, it is reasonable to encourage agricultural land use; planning and interest has risen in the cultivation of non-food crops in marginal lands to overcome these conflicts. This approach is a promising option to sustain and improve rural development, especially in areas threatened by abandonment, helping to regenerate those sites while bringing additional revenue to owners (Schröder et al., 2008). Tolerance to marginal soils and even to soils degraded by anthropogenic interventions (e.g. contaminated soils with heavy metals) have been suggested for perennial grasses, such as Miscanthus spp. and giant reed (Barbosa et al., 2015, Bosco et al., 2016), short rotation coppices, such as poplar trees (Redovniković et al., 2017) and annual crops, such as hemp, flax and kenaf (Pandey et al. 2016) among other non-food crops. Although yields and biomass quality can be affected by the marginality of the soils, compromising its economic exploitation, its cultivation may contribute to improve the quality of soil and the biological and landscape diversity (Barbosa et al., 2018).

4. Biodiversity & Landscape

Management practices that limit soil disturbance and fertilization and promote plant diversity are likely to result in more and sustained ecosystem services. Additionally, the landscape surrounding individual fields is an important determinant of the types of ecosystem services that are provided from industrial crops.

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Marginal lands, where soil fertility or other factors limit crop production may offer opportunities to support these crops, without reducing food production (Landis et al., 2018).

The adoption of industrial crops systems to supply feedstocks to bioenergy and bioproducts industries has the potential to alter the mix of ecosystem services realized from agricultural landscapes; enhancing habitats for both grassland birds and beneficial insects (Gasparatos et al., 2011).

Many studies have identified the important role of perennial and woody species, especially in supporting biodiversity in general and beneficial organisms in particular (hemp, camelina, aromatic plants, miscanthus, willow). Evidence suggests that management systems that emphasize crop diversity through the use of polycultures, cover crops, crop rotations and agroforestry can often reduce the abundance of insect pests that specialize on a particular crop, while providing refuge and alternative prey for natural enemies (Perfecto & Vandermeer 2008; Andow 1991). Similar practices may benefit wild pollinators, including minimal use of pesticides, no-till systems and crop rotations with mass-flowering crops. Hemp flowering cycle usually occurs between July and September, coinciding with a lack of pollen production from other farm crops. Being a wind pollinated, dioecious and staminate plant, cannabis produces large amounts of pollen, a vital nutritional source for bees during periods of floral scarcity.

Some industrial crops (lavender, rosmarinus, camelina, hemp and willow) have low input requirements and their cultivation is associated with very low GHG emissions, especially perennials, with the ability to recycle and store nutrients over winter in underground roots and rhizomes; they have comparatively low fertilization requirements. In addition, apart from herbicides during the first establishment years, most industrial crops require less, if any, pesticide application for healthy growth (Cosentino, 2015).

The more complex structure and heterogeneity of a vegetation system have a positive influence on its cover value for wildlife and any natural vegetation type has the best performance concerning the ecosystem services and, consequently, biodiversity, contrarily to the establishment of a monoculture. Therefore, native species (e.g. cardoon, reed canary grass, rapeseed) and colourful blossomed crops (e.g. oil crops, lavender, flax, cardoon) contribute to the biodiversity value and perennial grass and tree plantations also, because they provide more shelter to microfauna, soil fauna and bird species. Some crops have been reported as a source of biodiversity loss. For example, sugar beet is penalized, since it does not provide relevant structure and its harvesting is very aggressive to soil fauna owing to the total removal of the plant. Reed canary grass and giant reed are aggressive crops and present an invasive character. Moreover, eucalyptus is also penalized because its allelopathy further limits the development of native vegetation. In terms of landscape diversity, variation is considered a benefit when it embraces gains in structure (perennials, trees) and/or colour (blossoming crops), and ground hugging crops, as sugar beet, represent a downgrade. (Fernando et al., 2010)

5. Water

Crops can either be irrigated or suppress their water needs by accessing aquifers and precipitation water. Whichever way, unless rainfall tops requirements, freshwater must be extracted from surface or groundwater, which depletes natural stocks. Hence, depletion of groundwater resources can be determined by comparing the available water provided by rainfall and the water requirements of the crop. Concerning industrial crops, the study of Fernando et al. (2010) showed that crops, such as perennial herbaceous, short rotation trees and oil crops, such as ethiopian mustard, rapeseed and sunflower, do not inflict a depletion of groundwater resources. Yet, other crops, such as sugar beet, sweet sorghum, and hemp may lead to depletion of groundwater resources, especially in regions with less precipitation, such as the Mediterranean, where balances results can be lower. Therefore, reduction of the environmental impact on water resources can be accomplish through a correct adequacy between crop and location.

Hydrology effects of energy crops cultivation can go beyond their water demand, focusing also on the crops cultivation effects on the flow of ground water, stream water, run-off, etc. Although these aspects are highly site specific, they are also related to crop traits. There are overall conclusions pointing towards neutral to beneficial effects. Soil covering minimizes surface run-off and sediment and nutrient losses, and perennials, due to longer permanence in the soil, will have a beneficial effect. On the opposite, crops with shorter permanence in the soil have a higher impact on hydrology. However, species combining higher growth rates, transpiration rates and water needs, longer seasonal growth and deeper and more complex root system (e.g., perennials, hemp and sweet sorghum), slow down rainfall refill of aquifers, which may represent a shortcoming (Fernando et al., 2010, 2015).

In 2005, the Stockholm Environmental Institute conducted a study comparing the ecological footprint of producing hemp, cotton, and polyester. The results show hemp being more ecologically neutral than other fibres, particularly in water usage. As an example, cotton requires 9,758 kg of water per kg while hemp needs between 2,401 and 3,401 kg of water per kg. This represents a 75% water saving. Hemp produced for textile uses significantly less water and chemicals than cotton.

6. Inputs & Resources

In the face of climate change, resilient agricultural systems with limited fossil fuel inputs will be needed (Lin et al. 2008). Sustainable intensification through the management of ecosystem processes has the potential to increase food production while minimizing some of the negative impacts of agricultural intensification on biodiversity and ecosystem services (Baulcombe et al. 2009).

Low-input farming systems seek to optimize the management and use of internal production inputs and to minimize the use of external production inputs (fertilizers and pesticides), wherever and whenever feasible and practicable, to lower production costs, to avoid pollution of surface and groundwater, to reduce pesticide residues in food, to reduce a farmer's overall risk, and to increase both short- and long-term farm profitability (Parr et al., 1990).

Agricultural systems rely on a supply of synthetic fertilizers, that in turn depend on the input of mineral resources and pesticides that end up in soil, water and air, and may cause noxious human health effects, damage to flora and fauna, contamination of soil and groundwater and encourage development of pests and diseases. In this respect, as most of the industrial crops present low susceptibility to pests and diseases, they also need low amounts of pesticides. Yet, pesticides application penalizes some crops, e.g. sugar beet and cotton. The choice of pesticides presenting less impact to soil and water can be an option to reduce the environmental burden. Regarding fertilizers use, perennials are less N, P and K demanding than annuals, thus showing lower impact regarding inputs and mineral resources exploitation. Yet, differences to most of the annual crops are not significant.

7. Environmental benefits of industrial crops – summary

7.1 Soil & carbon sequestration

The importance of soil and soil quality is highlighted in many documents and scientific publications. The EU Mission *"Caring for Soils is Caring for Life"* states "Land and soils are essential for all life-sustaining processes on our planet. They are the basis for the food we grow as well as for many other products such as feed, textiles, or wood" (European Commission, 2020). The main question is how to improve soil quality, increase its fertility and make it a sustainable resource for multifunctional biomass crops.

The non-food crops play a significant role on soil quality improvement and carbon sequestration. The Intergovernmental Panel on Climate Change methodology for the calculation of greenhouse gas emissions from agricultural soils suggests that growing perennial herbaceous crops have high potential for carbon sequestration in the soil (IPPC, 2006). It has to be stated that the rate of carbon sequestration in non-food crops plantations varies very much between used agricultural technologies. For example, biomass of crops harvested in autumn contain more nutrients compared to those harvested in spring. Usually, most of the leaves fall on the ground till the spring harvest and soil quality is improved by increasing the content of organic matter and nutrients, which are mineralized. It has to be noted that the potential of carbon sequestration is influenced on crop species and genotypes, agricultural management and growing conditions. In warm climate conditions, most non-food crops produce higher biomass yield and have higher potential for carbon accumulation. On the other hand, if non-food crops are grown under dry environmental conditions, they may influence the carbon reduction in the soil (Liu et al., 2014). Therefore, the selection of growing non-food crops may be evaluated according to many environmental factors.

7.2 Water

Water use efficiency plays a significant role in many agricultural management systems. Most non-food crops have quite good water use potential, and may be grown in dry weather conditions, but some research papers state that growing them in dry conditions is not sufficient (Malesky et al., 2019). Nevertheless, most non-food crops, especially perennial ones, are high-yielding crops which have relatively long roots and might lead to deep-soil water depletion (Malesky et al., 2019).

No less important is not only water use efficiency, but also water quality. High-yielding crops are usually grown in contaminated soil for the reduction of heavy metal content and other pollutants in the soil as well reduce their leaching to water. For this reason, much more attention has to be given to the short rotation trees and other woody crops. The accumulation of pollutants in biomass could be a solution for cleaner water.

7.3 Air

Air quality is the key-important for people's wellbeing. The content of greenhouse gases in the air is increasing in the past few years and more solutions to clean the air have to be found. In 2013, Finnan and Styles indicated that "Extrapolated up to the EU scale, replacing 25% of oilseed rape and sugar beet production with hemp production could increase the net of GHG abatement by up to 21 Mt CO_2eq./year." (IPCC, 2006). Schmidt and collaborators (2015) indicated in their study that the use of perennial grasses for stationary heat and power generation can achieve up to 13 t CO_2 eq./(ha · year) of greenhouse gas emission savings. Considering that these crops were cultivated on marginal land this is a substantial achievement. Therefore, it could be stated that the use of some industrial crops for non-food purposes could be promising for the reduction of GHG.

As perennial herbaceous non-food crops are low-maintenance crops and need lower-energy input requirements (fertilizers, pesticides, etc.), the resulting reduction of GHG emissions and climate change mitigation, is usually more meaningful compared to annual crops (Fernando et al., 2018b).

8. Case Studies

8.1 Hemp

The real benefit of industrial hemp is usability produce different products with one crop: food, feed, cosmetics, biocomposites, paper, textile, building material, energy and phytomedicine. While seeds are particularly rich in high-quality proteins and have a unique essential fatty acid spectrum, flowers and leaves are rich in precious phytochemicals (cannabinoids, terpenes and polyphenols), promoting a healthy lifestyle.

Hemp-based construction materials have an exceptional thermal performance which reduces energy consumption, while sequestering carbon. They include hempcrete (a hemp-lime composite walling and insulation material), as well as hemp wool and fibre-board insulation. In addition, hempcrete is non-flammable, resistant to mould and bacteria, naturally regulates humidity and has an exceptional thermal and acoustic performance.

Several major European car manufacturers are already using hemp fibres in vehicle interiors (Hoodeh, 2017). Because, hemp is lightweight and as highly durable. Furthermore, hemp can be used for compostable packaging, which could contribute to a significant reduction in plastic waste.

The use of Hemp in the textile industry is not new at all: together with flax, hemp is one of the oldest natural fibres used by humans. For centuries, hemp fabric was used not only for clothes, but also for the sails and rigging on ocean–going ships, because of its resistance to salt (Kramer, 2017). Nowadays hemp fabrics are becoming more popular because they are breathable, naturally antibacterial, resistant to UV light, mould and mildew, and extremely durable.

Approximately 80% of hemp paper produced today is used for cigarette papers, but it has the potential to be used more widely as heavy-duty cardboard, food packaging, sanitary papers and also for filtration and absorption purposes. Past applications included a wide range of everyday products including banknotes, bank bonds and stamps. Furthermore, hemp paper can be recycled 7-8 times, compared with only 3-5 times for wood pulp paper. Hemp paper does not necessarily require toxic bleaching chemicals as the whitening can be achieved with hydrogen peroxide, however, there are other agents more preferable such as oxygen, ozone, peracids and polyoxometalates.

A high biomass rate of hemp corresponds to higher carbon storage potential. Hemp grows rapidly (4 to 5 months), is tall (up to 5 meters) and deep rooted into the ground (up to 3 meters): it is indeed a perfect crop for storing carbon.

One tonne of harvested hemp stem contains 0.7 tonnes of cellulose (45% carbon), 0.22 tonnes of hemicellulose (48% carbon) and 0.06 tonnes of lignin (40% carbon). Consequently, every tonne of industrial hemp stems contains 0.445 tonnes carbon absorbed from the atmosphere (44.46% of stem dry weight). Converting carbon to CO_2 (12 t of C equals 44 t of CO_2), this represents 1.6 tonnes of CO_2 absorption per tonne of hemp. On a land use basis, using a yield average of 5.5 to 8 t/ha, this represents 9 to 13 tonnes of CO_2 absorption per hectare harvested (Hayo et al., 2008).

8.2 Poplar

Due to its low-input requirements in comparison to annual crops, poplar plantations has many positive environmental impacts while the risk of negative environmental impacts is generally very low.

The positive effects on soil quality, when short rotation crops (SRC), including poplars, is cultivated instead of agricultural crops, have been mentioned as one of the great advantages of poplars (Dimitriou et al., 2015):

- Carbon (C) storage in soil organic matter is higher under SRC than under conventional agricultural crops such as cereals or intensively managed grassland.
- Soil organic matter stability is higher under SRC than under conventional agricultural crops and supports C sequestration in the soil.
- Soil erosion is lower under SRC than under conventional agricultural crops.
- Total soil N content is higher and the proportional nitrogen (N) availability for plant growth is lower, caused by an increased C/N ratio of soil organic matter under SRC than under conventional agricultural crops.
- Phosphorus (P) availability to the plants is lower under SRC than under conventional agricultural crops.
- The bulk density is slightly higher under SRC than under conventional agricultural crops.
- The soil pH can be slightly lower under SRC than under conventional agricultural crops.
- The microbial activity is slightly lower than the new biomass (leaves, roots) is created. This contributes to the accumulation of organic matter compared to the soil under conventional agricultural.
- Cadmium (Cd) concentrations in the soil under SRC are lower than under conventional agricultural crops.

Research in US show, that soil carbon under hybrid poplar stands increase from between 9% in heavier soils to 62% in sandy soils, compared to adjacent soils with annual cropping. Values for soil carbon ranged from 4 to 15 Mg ha, with the lower value being found in sandy soil (Tuskan, 2001).

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Poplars are generally considered as a crop that improves the water quality. The impact of poplar in water quality has been mainly studied concerning leaching of nutrients; without determination of chemical compounds as pesticides in the groundwater, since the use of pesticides in poplar plantations is limited.

The analysis conducted in Sweden (Dimitriou at al., 2017) revealed that cereals and grassland showed higher NO3-N concentrations in the groundwater than in poplar plantations. In the case of cereals, the NO3-N was particularly high, nearly five times higher median concentrations than in the case of poplar fields. Concerning PO4-P, the concentrations were also lower in poplar fields, although these differences were only significant when using grasslands as reference fields.

Due to poplar extensive fine root systems readily take up N in combination with low N leaching to the groundwater, poplars has been used to treat and utilize N-rich wastewaters such as municipal wastewater or landfill leachate, but also solid residues such as sewage sludge (combined with the ability to take up heavy metals). There have been extensive research evaluating leaching of N but also of P from such practices when very high N amounts have been applied trying to optimize the systems (e.g. up to 300 kg N/ ha year), with the results very low leaching from SRC.

This indicates the potential for using poplars in intensively managed agricultural areas to reduce nutrient leaching either by replacing existing crops or by using poplars as buffer zones between intensively managed arable land and water bodies to reduce surface run off and groundwater leaching.

Poplar plantations grown on agricultural land can improve biodiversity at the landscape level, in particular if the plantations are established instead of cereals and spruce or fallow ground in a homogeneous agricultural landscape. For example, compared to managed coniferous forests and farmland in boreal Sweden, young poplar plantations, especially if not too large in size, have been concluded to increase vascular-plant diversity (Gustafsson, 1987; Weih et al., 2003). Similar to the observations on floras, fauna diversity (birds and mammals) is frequently found to be higher in poplar plantations compared to agricultural croplands (Christian et al. 1998, Berg 2002). Thus, the more extensive management of poplar plantations compared to intensively managed cereal crops can improve habitat quality for many organisms, including plants and birds (Christian et al., 1998; Berg, 2002; Weih et al., 2003; Dhondt et al., 2004). Some concerns are raised regarding the impact of plantations of poplars on the landscape. However, if used creatively as part of active landscape analysis and design, plantations of poplars can improve greatly the visual and recreational values of a landscape and can improve the aesthetic perception of homogeneous agricultural landscapes by adding variation and structure (Rode, 2005).

In order to ensure, that Poplar plantations are established and managed in a sustainable way, that preserves high conservation values, intact landscapes, avoids pesticide use, and provide valuable ecosystem services, poplar plantations can be certified for their sustainable use. Recently the new tendency from wood processing industry and energy sector (as required by new Renewable energy directive) can be observed that industrial and energy wood users more and more often require certain sustainability proof (certificates) for raw material procured. This concerns both resources from conventional forests and SRC.

One of the most widely used sustainability certification schemes for wood resources is Forest Stewardship Council (FSC) certification, which has developed Plantation standard to be applied for poplars and other SRC. Currently poplar plantations according FSC regulations are widely certified in the US and other countries, and first steps have been taken already in the EU (Slovakia, Lithuania).

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EIP-AGRI Focus Group
Sustainable industrial crops

MINI PAPER 2: Selected value chains on industrial Crops

JANUARY 2021

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1. Introduction

Industrial crops can provide abundant renewable biomass feedstocks for the production of high added-value bio-based commodities (i.e. bio-plastics, bio-lubricants, bio-chemicals, pharmaceuticals, bio-composites, etc.) and bioenergy.

According to MAGIC project (**www.magic-h2020.eu**) the industrial crops can be categorized to oilseeds, lignocellulosic, carbohydrate and specialty crops (aside figure).

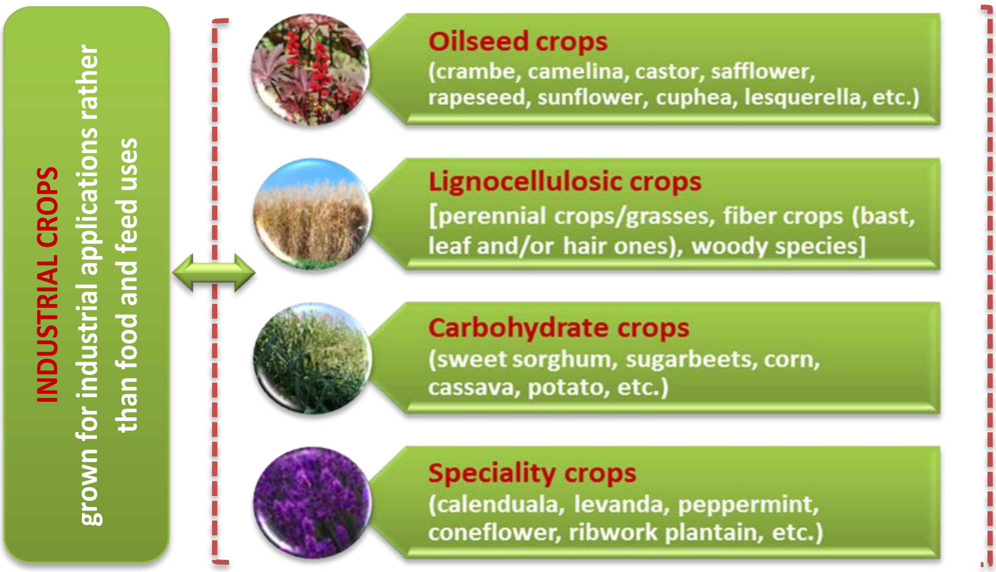

Figure 1. Categorization of industrial crops (source: MAGIC project).

A key issue in the successful insertion of the industrial crops in EU agriculture is the organization of their value chains. In this mini-paper selected value chains for eight industrial crops are being presented: **two oilseeds industrial crops** (camelina and castor bean), **two perennial grasses** (miscanthus and switchgrass), **two fiber crops** (cotton and industrial hemp), **one woody species** (poplar) and **one specialty crop** (lavender). These industrial crops have been selected because: a) they are already been grown in Europe in large or small areas like cotton and industrial hemp respectively, b) they are considered ready for practice and farmers can improve their profitability and sustainability by introducing crops like camelina, miscanthus, poplar and lavender and c) practitioners need concrete information to get familiar with and cultivate them successfully. This mini-paper is only a starting point and further activities and/or information are needed to cover farmers needs for those industrial crops are ready or near to agricultural practices. These activities/actions could be targeted projects with strong farmers' participation, such as EIP operational groups for instance, where demonstration activities should be included as well as supporting information like videos, growing guidelines, etc.

2. Oilseeds (camelina & castor bean)

2.1 Camelina value chain

Camelina is a unique oilseed crop from the Brassicaceae family, typically requiring low inputs, with modest nitrogen fertilization[1], little herbicides and usually no pesticide or fungicide applications. Camelina is

[1] Camelina fertilization requirements per 1.000 kg of seed per hectare: N: 37 kg/ha, P_2O_5: 30 kg/ha, K_2O: 40 kg/ha

characterised by its resilience, especially under drought stress conditions: camelina shows better water efficiency than other oilseeds, especially for low rainfall conditions (< 250 mm) [1]. Camelina also provides other agronomic advantages when introduced in farmer's rotations, including good allelopathic effect[2] allowing weed competition and better tolerance to pests [3] than other crucifers such as rapeseed. From an environmental perspective, camelina's root system helps improving the soil structure and it is a melliferous species, providing a source of nectar and pollen to bees at a critical moment of the year [4].

Although camelina oil could potentially have many applications, over the last 30 years the patents filed are mainly concentrated on two industries: the biofuel and cosmetic industries. Indeed, camelina oil is currently employed in different cosmetic formulations[2]; however, its current demand is contained to a small niche market. On the contrary, camelina oil sustainably produced for the biofuel industry would benefit from a tremendous market demand.

In December 2018 the revised Renewable Energy Directive 2018/2001/EU (RED II) entered into force, setting the target for advanced biofuels to increase to 3.5 percent in 2030, which requires an immense quantity of sustainable feedstock, reaching 10 million metric ton of oil equivalent[3] according to the European Technology and Innovation Platform.

The RED II also defined "intermediate crops, such as catch crops and cover crops, provided that the use of such intermediate crops does not trigger demand for additional land". Intermediate crops currently not considered as food and feed crops category[4].

One of camelina's main differentiating characteristics as an oilseed crop is its precocity, as there are European varieties that have been developed for cultivation in 80 to 90 days from sowing to harvest[5]. Based on such plasticity, camelina can be sustainably introduced in different farmer rotations as a catch crop (grown between successive plantings of main crops) to produce camelina oil for advanced biofuels. In Europe there are several catch cropping schemes that are already being developed in a commercial scale:

Southern Europe - Replacing fallow land in high risk desertification areas

Camelina can be introduced as an autumn crop, replacing fallow land periods in cereal monocultures in EU arid regions with high desertification risk and low organic matter content. This is particularly relevant in Southern/Mediterranean Europe, where strong evidence exists of irreversible desertification effects. These are impoverished areas which are typically characterized by cereal monoculture production in rotation with fallow land. Farmers require an alternative oilseed crop to improve soil structure, nutrient cycling, fertilizer efficiency, weed control while reducing soil degradation. During the **ITAKA** project more than 15,000 hectares have been cultivated between 2013 and 2016 under these conditions in Spain. Camelina Company has cultivated to date over 40,000 hectares with more than 1,000 farmers in this rotation scheme in Spain. The cultivation potential in Europe is as high as 8.5 million hectares available, in European Mediterranean regions according to the **S2Biom** project. Central Europe –

[2] L'Oréal has marketed over 450 products with camelina oil in its formulation. Camelina Company España communication.
[3] EU Biofuels Annual 2019, European Technology and Innovation Platform.
[4] RED II Annex IX Feedstock Evaluation (ENER/C1/2019-412).
[5] Camelina Company España communication (www.camelinacompany.es).

Summer catch crop

Short cycle camelina varieties can be cultivated during the summer in Central Europe as a catch crop, improving soil health while avoiding nitrogen leaching, a major concern in these agricultural areas. Camelina Company España has launched in 2020 a commercial pilot of over 2,000 hectares in Central Europe. The cultivation potential exceeds 10 million hectares available in the EU, introducing camelina as a catch crop following a winter cereal or legume harvest.

Camelina cultivation can be performed with existing farmer cereal machinery, from sowing to harvest, simply fine-tuning it for small seeds. Additionally, camelina harvest can be fully processed leveraging on existing agricultural and crushing infrastructure for major oilseeds, such as rapeseed or sunflower.

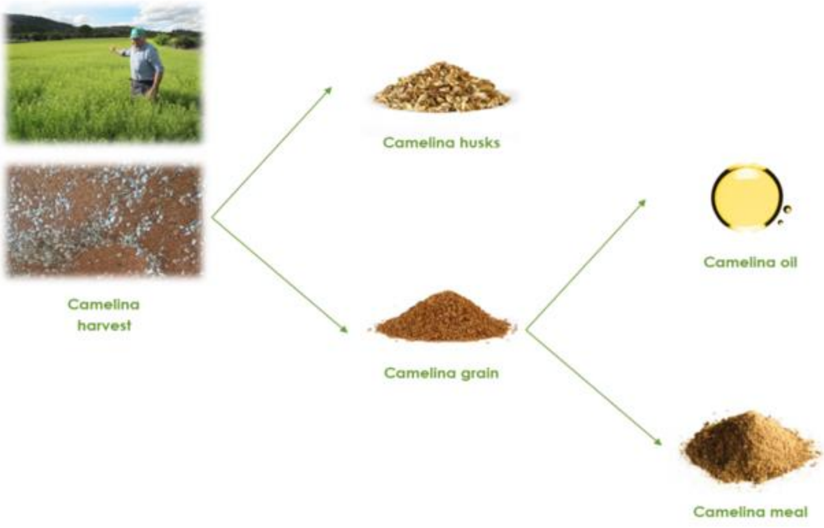

Figure 2. Value chain of camelina (prepared by Camelina company)

A camelina farmer produces camelina grain, husks (or siliques) and straw, typically in a proportion 1:1:2. As the harvest usually contains 10% to 20% of camelina husks, the industrial process followed from the harvest up to the crushing facility includes a cleaning process to separate camelina husks from camelina grain. The clean camelina grain is transported to the crushing facility for oil extraction, producing camelina oil and meal. Camelina straw could be exploited for bioenergy.

Camelina husks main destination is the animal feed industry, due to its high fiber content (~35%). Within the ITAKA project camelina husks have been employed as raw material in ruminant's animal feed. The recommendation for **camelina straw** management is chopping the straw after harvest, in order to increase the soil's organic matter content. Alternatively, camelina straw is an interesting feedstock for energy applications -as it has higher levels of fiber and lignin and lower ash content than cereal straw-, especially in boilers.

Camelina grain contains typically 38-42% oil and 22-26% protein. **Camelina meal,** produced at the crushing facility as a solid by-product of the oil extraction process, is a remarkably interesting raw material for animal feed. Camelina meal protein content can exceed 40%, with approximately 2% fat content, situated between rapeseed meal (~33%) and soybean meal (~47%). In addition, the protein quality is high, as it shows similar digestibility to rapeseed meal for limiting aminoacids such as lysine and methionine. Animal feeding trials indicate that camelina meal [5] can be safely introduced at ~10% in broiler, laying hens, swine and cattle diets.

The key to increase camelina oil market value, while untapping large biofuel volume, and relies on its improved sustainability potential. As indicated, camelina oil must be produced as a catch crop, which will enable to access a market premium for non-food and feed feedstock as well as potentially the double counting associated with RED Annex IX. As camelina biofuel can reduce up to 80% Greenhouse gas (GHG) emissions compared to it's petroleum counterpart [5], an additional market premium can be obtained for camelina oil produced under cultivation practices which allow for high GHG emission savings.

The value for the farmer relies on introducing camelina as catch crop -not displacing any main crop-, benefiting this way from agronomic and environmental advantages, while having the opportunity to valorise its sustainable camelina harvest for advanced biofuels. This way, the more sustainable the farmer's practices are in terms of CO_2 emissions, the higher will be the value of his camelina harvest. Such approach is, additionally, fully aligned with the Green Deal's *A Farm to Fork Strategy* (May 2020) which aims rewarding farming practices that remove CO_2 from the atmosphere while providing farmers with a new source of income.

2.2 Castor bean value chain

Castor (*Ricinus communis* L., family Euphorbiaceae) is a valuable annual spring oilseed crop (around 80 cm high) with a growing cycle between 120 and 150 days when it is grown in the Mediterranean region. Its panicles are racemes up 40 cm long that produce 80 to 120 capsules each (3 seeds per capsule). In Figure 3 castor is presented at several stages of growth (source: CRES).

Figure 3. View of castor bean at several stage of growth (emergence, early stages of growth and seeds ripening) (source: CRES; Greece

Castor is being reported as a crop with tolerance to insects and diseases, nematodes, drought and heat, high and low pH, poor soil and slope. It is commercially grown in India, China, and Brazil. Currently, more than 3 million hectares of land are planted with castor around the world. Although the crop can be cultivated in the Mediterranean region, it is found only on experimental and demonstrative fields. It should be pointed out that Europe is one of the main importers of castor oil.

The crop can be grown on low rainfall and fertility conditions and it is considered appropriate for drying farming. Castor is a hardy crop and can be grown in a wide range of climates of warm regions with a rainfall of 250-750 mm. It performs best in moderate temperature (20-26°C) with low relative humidity and clear sunny days throughout the crop season. Areas with temperature higher than 40°C or lower than15°C are not conducive for castor cultivation. A frost free climate is mandatory for the crop. It is a drought resistant crop due to its tap root and due to light reflecting characteristics of its stems and leaves that reduce heat load and improve survival under moisture stress. The crop can be grown successfully on most of the soils apart from heavy clay and poorly drained soils. Moreover, soils with low water holding capacity like the sandy soils are also not appropriate for castor cultivation. Soils with pH > 9.0 or < 4.0 should be avoided. Moderately fertile soils are preferred as high fertility induces excess vegetative growth, prolonged flowering and delay the maturity, leading finally to poor yields.

The last years a number of hybrids have been developed that are short with increased yields (up to 5 t/ha seeds, usually vary from 2 to 5 t/ha seeds and oil content 48 to 50%), uniform seed maturity, increased tolerance to pests and diseases and increased performance to mechanical harvest.

A deep ploughing is necessary, for weed control and conserving moisture followed by harrowing. It has been recommended to sow in rows with 1 m distance between the rows and 25 cm within the rows; 15 kg seeds/ha for sowing. In general, it can be said that the distances between the rows should be large varying from 60 to 100 cm, while within the rows should be between 15 and 60 cm (12-15 kg seeds per ha). The soil depth at sowing varies according to the soil type from 6 to 10 cm. Shallow soil depth at sowing (6 to 8 cm) is recommended in heavy soils. The soil temperature at sowing should be higher than 12°C.

Castor exhausts the soil quickly. It has been estimated that for the production of 2000 kg seeds/ha is removed from the soil: 80 kg/ha N, 18 kg/ha P_2O_5, 32 kg/ha of K_2O, 13 kg/ha CaO, and 10 kg/ha of MgO.

The harvesting should be done when the capsules turn to yellow-brown. The seeds do not mature at the same time and in most of the cases the plantations should be sprayed in order the growth to be stopped and the harvesting to be scheduled. Castor seeds are very susceptible to cracking and splitting at the maturity stage. Thus, adjustment to the combine cylinder speed and cylinder-concave clearance is very important. Usually, a low cylinder speed and wide cylinder concave clearance are recommended. Combine operators should frequently inspect harvested beans for breakage. At the harvest seed losses up to 30% have been recorded. The harvesting mechanization of castor oil is still an unresolved problem. The problem is mainly related to the fact that the traditional varieties are very tall, have several racemes, and capsules ripening over a period of 2 months, which makes 2-3 manual harvesting per season necessary. Breeders worldwide are developing new varieties with characteristics that permit the introduction of harvesting mechanization. Once this is achieved, either conventional combines equipped with a modified maize header (to prevent seed losses) or purpose-built castor headers [6] could be used. However, since castor beans are very susceptible to cracking and splitting during harvest, adjustment of the combine (e.g. cylinder speed and cylinder-concave clearance) is very important [7].

Castor beans are transported to a processing/storage facility. In case of manual harvest, a de-hulling step is necessary. The empty capsules (~1/3 of the harvested biomass) are briquetted and used for bioenergy purposes. In case of mechanical harvest (using a combine), the empty capsules remain on the field and are ploughed in. They maintain soil fertility and thus substitute for conventional mineral fertilisers. The protein-rich press cake cannot be used as animal feed since it contains several toxic compounds. Therefore, it can be used as fertiliser.

Figure 4. Castor bean value chain tested in Romania by CREA (MAGIC project).

In MAGIC project the value chain of castor bean is being developed with a large field trial established in Romania in 2019 (Figure 4) that will be further analysed in another field trial that will be established in central Greece in spring 2021 and will be operated by CREA and CRES (Center for Renewable Energy Sources and savings)

3. Perennial grasses

3.1 Switchgrass value chain

Switchgrass is a warm-season perennial grass belonging to the Poaceae family (Kingdom: Plantae, Order: Poales) with a lifespan 10-20 years depending on the area of its cultivation. It is established by seeds. The plant has erect stems with a height that could vary from 0.5 to 2.7 m. Switchgrass plants have a deep root system that can be up to 3 m depth.

In Figure 5 the crop is presented at several stages of growth. Initially, switchgrass has been selected as a promising forage crop. Switchgrass has been selected as promising energy crops for USA (for lignocellulosic feedstock production (combustion, conversion to liquid or gaseous forms) in the beginning of 1980s and a decade later the research was started in Europe in the view of "Switchgrass for Energy" project. Thereafter, the crop has been investigated in Bioenergy Chains project and recently in OPTIMA project.

Based on the morphology and the habitat of natural switchgrass populations, two main ecotypes have been classified; **upland** and **lowland** ones. *Lowland ecotypes* are taller than upland and they have longer bluish-green leaves and have longer ligules. The *upland ecotypes* are better adapted to colder and drier habitats, while the lowland ones tend to thrive in warmer and wetter habitats.

Switchgrass can grow under variable soil conditions ranging from sand to clay loam, although it grows best on well-drained fertile soils. Switchgrass tolerates acid and infertile soils conditions that could not be used by cool-season grasses. Although it grows best in soils with neutral pH it has been reported in some research works that the crop tolerates soil with pH from 4.9 to 7 as well as alkali soils (pH 8.9 to 9.1).

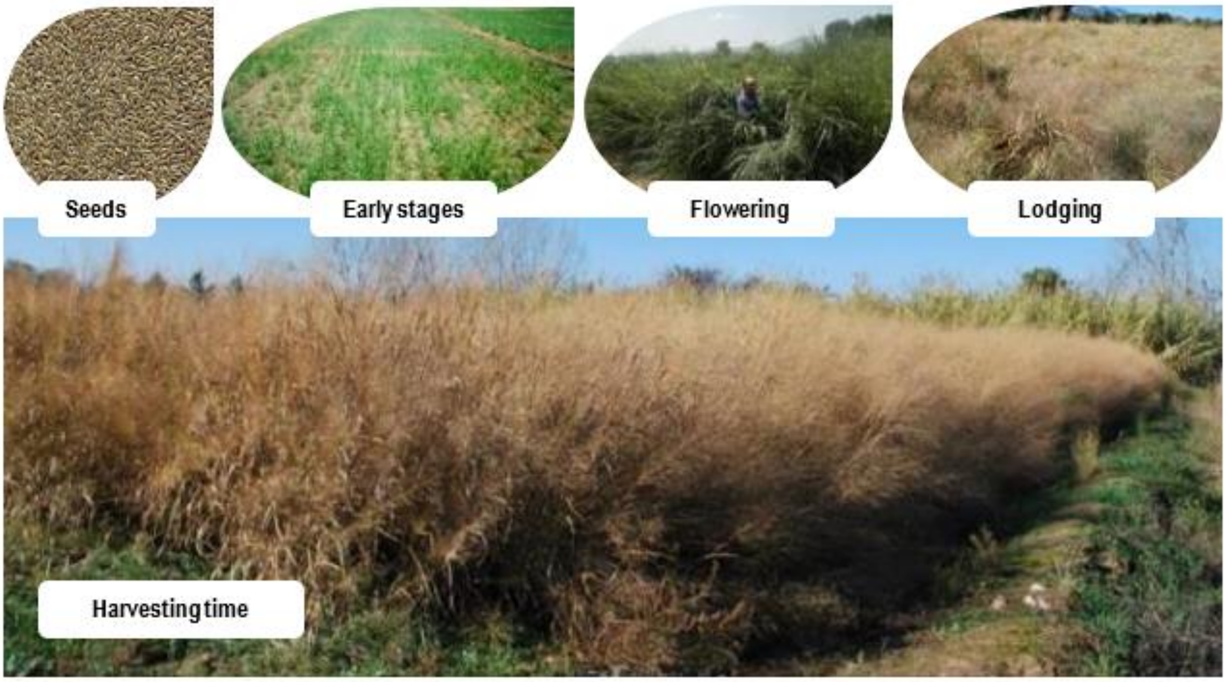

Figure 5. Switchgrass at several stages of growth (source: CRES, OPTIMA project)

A firm seedbed is recommended for proper seed placement regardless of planting method since switchgrass is planted at a shallow depth. Planting switchgrass using conventional tillage methods is a common practice for effective establishment. Conventional tillage can control or reduce cool-season weed populations and reduce residue from previous cropping systems. Conventional tillage should be avoided on fields with steep slopes because of the risk of soil erosion. For bioenergy purposes, both pre- and post-emergence herbicides are critical under no-tillage practices to control or reduce weed populations during the establishment year.

The proper planning is a key factor for the successful establishment of the crop. The main factors that should be considered for a successful crop establishment are: seedling depth, soil texture, soil moisture, and soil temperature. The recommended planting depths for switchgrass could be varied from 0.2 to 2 cm but many studies agreed that the soil depth should be no deeper than 13-mm depth. At sowing high germination rates could be ensured if the soil temperature is around or higher than 20^0C. The recommended seedling rates for switchgrass are 200-400 pure live seeds (PLS) m-2. Several row spacing (15-70 cm) have been tested.

Switchgrass demonstrates broad tolerance to soil moisture availability by germinating, establishing, and reproducing under both moisture deficit and flooded conditions. It have been reported that much of eastern North America is highly suitable for switchgrass production, while areas with Mediterranean climate are unsuitable without irrigation.

Yields up 20-24 t/ha have been reported on annual basis with 20-30% moisture content. Usually, the yields maximized in the 2nd or the 3rd growing period. When switchgrass is being cultivated on marginal land the mean yields varied from 10-12 t/ha. Lowland varieties were productive in the Mediterranean region.

The selection of the optimal harvest and post-harvest management practices for switchgrass is strongly depended on the end-use. Although switchgrass management as energy crop is relative new, harvesting and baling could be done with commercially available haying equipment, after some modifications. It is recommended that the cutting height for switchgrass should be higher than 10 cm, which keeps the windrows elevated above the soil surface to facilitate air movement and more rapid drying to less than 20% moisture content prior to baling. The harvested material can be balled in large bales, round or rectangular, for storage and transportation. The round bales are suggested when switchgrass is going to be stored outside since they tend to have less storage losses compared to rectangular bales. The rectangular bales are easier to handle and load a truck for transport without road width restrictions.

Figure 6. Harvesting of switchgrass in Italy (Agricultural University of Bologna, Bioenergy chains project)

The harvested biomass has a Gross calorific value (MJ/kg) varied from 18.30 to 18.90 (net calorific value 17.0 to 17.6). The ash content varied among the tested varieties and could be varied from 3.85 to 5.40%. When the harvesting takes place quite late in the season (January to February) the nitrogen content of the harvesting material is quite low (<0.25%).

Initially switchgrass had been selected in 1940s as a forage crop for grazing or hay. In 1980's switchgrass has been proposed as an ideal energy crop for lignocellulosic feedstock production (combustion, conversion to liquid or gaseous forms). Nowadays, switchgrass is being investigated also as source for fiber or pulp for paper, for phytoremediation, for biomaterials, bioproducts, etc. The lignocellulosic feedstock that can be produced from perennial grasses like switchgrass has been considered as low cost biomass compared to oil, sugar and starch-rich crops and fits well to the modern bio-based economy concept to promote bio-refineries. Switchgrass has been listed in the latest EU directive 1513/2015 for the promotion of advanced biofuels, whose energy potential has been considered to be twice than the first generation biofuels. Bioethanol produced from lignocellulosic feedstock show enormous potential as an economically and environmentally sustainable renewable energy source.

Native prairie grasses are commonly used in phytoremediation strategies. Their extensive fibrous root system can penetrate up to ten feet below the surface and can result in a greater surface area than other vegetation. Phytoremediation studies have shown that switchgrass, alone or in combination with other native prairie grasses, is capable of removing atrazine from the environment.

3.2 Miscanthus value chain

Miscanthus is a perennial rhizomatous grass, native to East Asia, with high biomass yield potential. Miscanthus x giganteus is presently the only commercially grown miscanthus genotype, which is a hybrid between *M. sinensis* and *M. sacchariflorus*. Miscanthus x giganteus is being established by rhizomes and/or platlets. Its biomass has valuable applications in different end-uses mainly related to energy production.

Figure 7. Miscanthus from early stages of growth (at the establishment year) till the final harvest

It can be grown in whole Europe successfully. Currently, its cultivation area in Europe is around 25,000 ha and is mainly located in UK, Germany, Switzerland, Poland and France. It is suitable for a wide range of soils and best produced where pH is between 5.5 and 7.5.

Miscanthus can grow as tall as 3m and its low mineral content and high biomass yield (Figure 7) makes its suitable feedstock for both energy (heat, electricity and bioethanol) and non-energy purposes (animal bedding, paper and bioplastics) [8]. It is found to be very beneficial for soil erosion mitigation and allows high level of carbon storage in soil due to high level of plant residues from above and below ground.

It is a perennial crop (10-20 years) that regrows every spring. Miscanthus being a sterile crop is established in spring either with rhizomes or plantlets at 1-2 plants/m2. Rhizomes are sensitive to frost therefore should be planted before the frost period. The first year of the cycle is dedicated to the crop establishment with soil preparation, rhizomes planting (19,000 rhizomes/ha) and chemical weeding (if necessary). One more chemical weeding is applied the second year to ensure a good establishment of the crop.

In most cases weed control is needed only at the first stages of growth at the establishment year. There are efforts to upscale the seed-based establishment as it will be low costs and help meet the growing market demand [9].

funded by European Commission

Miscanthus needs average input of fertilizers. Although, it is reported as crop with high WUE (water use efficiency), irrigation is needed in order high biomass yields to be achieved on dry areas of south Europe.

Nitrogen inputs requirements are minimal and in winter most N remains in roots, rhizomes and litter. Nitrogen (N) fertilization is necessary mainly on soils with low N content. Nitrogen (N), phosphorus (P) and calcium (Ca) are about 2–5, 0.3–1.1 and 0.8–1.0 kg per t of dry matter of biomass produced.

Miscanthus requires very low use of chemicals for pests, diseases and weed management. It is reported that under European conditions, the pests and diseases problems are limited and the most important disease that has been reported is blight (mildew). Miscanthus can compete successfully with weeds once it has a good establishment.

Harvesting can be done once a year and harvested in the form of 3-4 meters high canes. The harvest is from December - March depends on the specific climatic region. Harvesting can be carried out using conventional farm machinery (e.g. self-propelled forage harvesters, etc.), producing either bales or chipped material.

Miscanthus chips can be stored well in covered storage but chips have some drawbacks like its low bulk density (150 kg/m^3), low fuel mass in combustion chambers, and potential bridging and clogging in automated feed systems. Pelleting is an option for Miscanthus and the highest pellet bulk density of 810 g/L can be achieved.

The yield of above ground Miscanthus biomass can be up to 16.3 ton dry matter/ha/year. In case of fully established 3-4 m tall miscanthus, the crop yield reaches up to 10-25 ton dry matter per hectare. Great photosynthetic activity and high biomass yield makes it ideal biomass crop.

In the view of MAGIC project a value chain for miscanthus is being examined as feedstock for pyrolysis oil, which is then used for the production of industrial heat. The complete value chain will be presented in the last year of the project (2021) and will be available on the project website **the project website**.

4. Woody species

4.1 Poplar value chain

Poplars (*Populus spp.*), the members of the Salicaceae family, are trees with many valuable characteristics which have led to multiple beneficial uses for society and the environment. In the EU, poplars are widely grown on over half a million of ha of planted and natural forests mainly in France, Italy, Spain, Hungary and Romania. Poplars are also cultivated as industrial crops over total 50 thousand ha area in Poland, Germany, Italy, France, Spain, Romania, Hungary, Slovakia, Lithuania, Sweden and other EU countries.

The success of poplar growing business is very much dependent on poplar clone selection, success of establishment, land quality, water availability and market conditions. The plantation establishment determines the overall quality of the plantation in long term. Land preparation, weed control and rainwater availability are the key success factors for the establishment of the plantations. Recent significant climate change consequences with repeating severe droughts pose significant additional risks for poplar plantation establishment and overall growth.

Poplar value chain starts from breeding as climate adapted poplar hybrids with high biomass yields are essential for poplar growing economics. *Populus nigra* and *Populus deltoides* hybrids mainly prevail in Southern part of the Europe, while cold tolerant *Populus maximowiczii* and *Populus trichocarpa* hybrids are being grown in northern part of Europe. Initially EU breeding programs were focusing on poplar hybrids for energy production, while recently more emphasis in breeding is provided to industrial grade poplar breeding, which may also be suitable for various biorefinery purposes.

As most of the poplars are established on marginal lands, the achievement of high yields requires intensive management, including fertilization (especially compensating lack of nitrogen on marginal lands). Poplar plantations form environmental point are very well suited for reusing of nutrient rich waste such as municipal water treatment sludge, biomass ashes, biogas digestate as poplars prevent nitrogen and other contaminant leaching. The EU LIFE project NutriBiomass4LIFE, implemented in Lithuania, demonstrates that even all municipal water treatment sludge of large cities can be used efficiently and without significant risks to the environment, while significantly improving biomass yields on marginal (non-fertile) lands.

Poplars are being established/planted based up-on the targeted markets and final products. This determines poplar planting design, clonal selection and rotation duration.

Energy or high density (10,000 - 15,000 short cuttings/ha) poplar plantations are being established for up to 3 year rotation to supply chips for renewable energy (heat and/or power) production. Such poplar plantations act as a part of local bioenergy value chain and are typically established to reasonable proximity to biomass boilers/CHPs as harvesting/chipping and transportation costs contribute to the most significant share of energy chip costs. Special poplar harvesting/chipping machinery are required to produce chips, therefore co-operation of smaller poplar growers is needed to make such an investment. Poplar plantations for energy are mainly being established in those markets, where wood chip supply from traditional forests is rather limited and where bioenergy for heat and power is not highly developed. Poplar plantations to supply energy chips are mainly established in Germany, France, Spain, Italy, Hungary, Poland and other countries. Energy chip market is pretty much vulnerable to oil price fluctuations; therefore this business loses its attractiveness during the down cycles of low oil prices.

Figure 8. Management, harvesting and products for poplar in Europe.

Industrial or medium density (1600 long poles/ha) poplar plantations are being established for 5-8 year rotation to supply pulp logs for pulp and paper and wood based board (particleboard, MDF) production. Even established at much lower density than energy plantations, medium density poplar plantations may have similar high biomass yield results over longer rotation. To accelerate growth, medium density poplar plantations are being established with long (150-180 cm) poles/rods. Such plantations are harvested manually or using small forestry machinery. As medium density poplar plantations produce revenues in longer rotations (what is not very attractive to farmers) typical investors in such plantations are industrial companies or financial investors. Farmers establish industrial poplar plantations having long term contracts with industries and even some pre-financing of establishment costs from industries. Such medium density poplar plantations are typically established to close (60-100 km) proximity to pulp mills, particleboard or MDF mills. Medium density poplar plantations are relatively new type of poplar plantations, with increasing popularity during last 10 years, and are established on wide scale in Poland, Romania, Hungary, Slovakia, Italy, France, and Lithuania. In Sweden poplar plantations to supply pulp-logs to pulp mills are established at 1000 plants/ha density and are being grown for 15-20 year rotation.

Veneer or low density (270 long pokes/ha) poplar plantations are being established for 15 year rotation to supply veneer industry. Veneer plantations are typically established with 6 m long poles/rods, at 6mx6m design, planted 2 m. deep. While growing poplars for veneer production special attention is given to pruning to grow high value veneer logs. The major investors in veneer plantations are the industry itself, while farmers grow poplars for veneer under long term contracts and pre-financing form industry. Veneer plantations are established in Southern part of Europe, where poplars are one of the major wood resources for wood industry: Italy, Spain, and France.

Poplars are also valuable resource part of new bio based industries value chains. Both sugars and lignin can be derived from poplars which are key raw materials for further processing into liquid biofuels, chemicals and various polymers. If using poplars in sugar platform bio refineries, industrial medium density (1600 long poles/ha) poplar plantations can be deployed as higher content of cellulose and hemicellulose can be derived from poplar stem rather than bark.

5. Specialty crops

5.1 Lavender Value Chain

Lavender (*Lavandula*) is one of the best known essential oil bearing plants, and is grown for oil, fresh flowers, dried products, food and other purposes [10,11]. The main comercial species are *Lavandula angustifolia* (lavender), *Lavandula intermedia* (lavandin) and *Lavandula latifolia* (spike) [10]. In this article we consider these three species.

Lavender, part of Lamiaceae family, is used in the pharmaceutical and therapeutic industry, cosmetics (perfume, hygiene and beauty products), odorants, cleaning agents, insect repellents and pests, or even in the interior or exterior design [12].

Lavender production is important not only for its economic contribution to farmers but also for its social and environmental role in the community and ecosystem, having few, if any, insect pests and fungal diseases. It is considered as a sustainable crop because it does not rely on pesticides and fertilizers, although in rare circumstances irrigation may be called for. The biggest issue is finding a viable marketing method.

Lavender can be a long-lived perennial, with a typical productive life of about 10 years, although plants have been known to live for 20 years, being best propagated from softwood cuttings of standard types.

Seed may not come true to type, and lavandin seed is sterile. The purpose for which the lavender is being raised heavily influences cultivar choice.

The most valuable substance extracted from *L. angustifolia* is essential oil [13], extracted by steam distillation of the flowers [14, 15]. Lavender oils contain more than 100 compounds. Linalool and linalyl acetate contents are two major constituents [16], and low content of camphor is very important because it gives lavender oil the undesirable odor [17]. Linalyl acetate is high in the lavender oil while linalool is higher in the lavandin oil. Lavender oil is mostly used for perfume, cosmetics and pharmaceutical industries [18, 19]. According to the European Pharmacopoeia reference values, lavender oil must contain linalool between 20-45%, linalyl acetate between 25-46% and less than 1.2% of camphor.

The essential oil of *L.angustifolia* is more expensive than other lavender species on the market because of its high quality and the plant's low yield of essential oil. The qualitative and quantitative composition of essential oil from *L. angustifolia* is variable and depends from genotype, climatic conditions, reproduction, or morphological characteristics. *L. latifolia* yields around three times more oil tan *L. angustifolia*. Thanks to its higher yield and ability of growing at lower altitudes its essential oil price is cheaper but the oil is of lower quality because of its dominant of camphor odour. The hybrid lavandin, *L. intermedia*, produces the largest quantities of oil of all species, but the oil is of lower quality as it has a distinct camphor scent [20].

The main producers are Bulgaria, France (these two countries together produce two thirds of total world lavender production) the United Kingdom, Spain, China and Russia. Italy, Morocco, countries of the former Yugoslavia, Hungary, Romania, Poland, Turkey, Ukraine, Moldova [20, 21].

Bulgaria has about 4 500 ha of production area and produced 200 tonnes of lavender oil in 2017, leading lavender oil producing and exporting country followed by France. France is the first country for lavandin oil production followed by Spain, with around 22000 ha of Surface devoted to lavender and lavandin, despite long-standing challenges experienced with *Stolbur phytoplasma disease.* Spain is the second big producer of lavandin oil behind France, with 2 000 ha and about 80 tonnes of oil. The country is a dominant producer of the essential oil of spike lavender *(L. latifolia*), with less than 10 tonnes a year.

Commercially France, Bulgaria, China, Russia and some other Eastern European countries are the most regular suppliers of lavender oil, and New Zealand can be considered as a newcomer to the world market [22].

Both lavender and lavandin essential oil are sold in two major ways:

i) local and niche markets and aromatherapy outlets run by smaller producers;

ii) international markets: targeted by larger producers or in cooperation with international companies. For those who intend to sell in international markets, it is necessary to follow established buyers, flavour and fragrance houses or companies in the essential oils business.

A growing number of distribution channels, particularly digital marketing/ online selling, has also contributed to the development of this sector. Consistent quality is needed to be a sustainable player in the market.

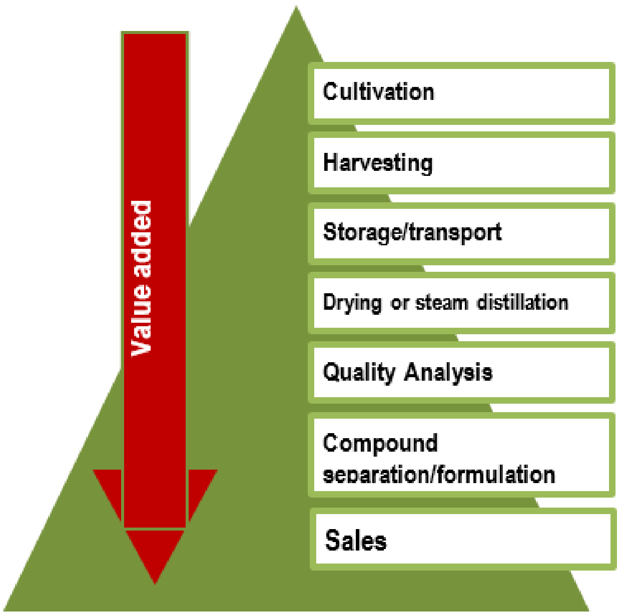

Figure 9. Lavender Value chain

As noted above, commercial-scale production of lavender essential oils relies on steam distillation. Steam distillation uses dry steam to vaporize and extract the oil.

Despite of the advantages described before, lavender value chain depends of distillation structure near productive areas and high level of mechanization (weed control and harvesting) to be cultivated.

Lavender oil production provides many opportunities for adding value for farmers and farm businesses (figure 9). The main adding values of lavender oil production are the essential oil itself, fresh flowers and plants, dried products, food and agro-tourism.

Easier farming, a moderate climate, the soil demand of the plant and high yield combined with state support have attracted many grain producers to become involved in the lavender business.

6. Fiber crops

6.1 The cotton value chain

Cotton is the largest fiber crop in the world, harvested in more than 30 million hectares; most of the world production is located in Asia. Cotton has been used for textile production for more than 8000 years and today is still the most important natural fiber at global level as it is the key material for the textile industry. Cotton is a high-demanding crop that needs large amount of water and nutrients and attracts many insects. Although only 2.4% of the world's agricultural land is used for cotton production, around 11% of pesticides and 24% of all insecticides globally are applied to cotton[6].

The cotton value chain is the backbone of the global textile sector, the quality of the cotton fiber has made this crop one of the most demanded for the production of cloth and textile products. Cotton represents a global market with well-established worldwide value chains where many countries of the world participate in. This value chain is normally oriented to produce high-quality fiber, but in the process, there are some other by-products with relevant value, especially oil and the seed cake for animal feed.

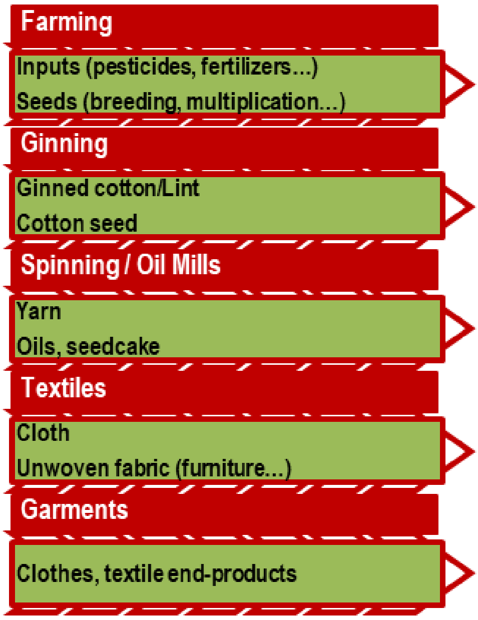

Figure 10. The Cotton Value chain

In the last years, the global market for cotton has been stagnated due to the fast increase in the consumption of synthetic fibers. This fast irruption has led to significant environmental problems caused by these synthetic fibers, especially the problem of microplastics which are released to the environment with the continuous use of these synthetic fibers. This problem has become very serious, with the ubiquity of these microplastics in all the oceans of the world. This need to shift from synthetic fibers is expecting to reduce the participation of the synthetic fiber in the global fiber consumption and hence provide better market opportunities for this crop. However, consumers and especially European consumers have rising concerns about the environmental sustainability of the production of their clothes which also concerns chemical-intensive crops such as cotton.

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[6] FiBL 2020 (https://www.fibl.org/en/themes/organic-cotton/organic-cotton-background.html)

In Europe, even if its participation in global production accounts for less than 1%, it is still one of the largest industrial crops in Europe in terms of cultivated area. It represents more than 300.000 hectares shared between Greece, Spain, and to a lesser extent Bulgaria. Due to agro-ecological, historical and political reasons this crop has been granted with a specific CAP support scheme since the accession of Greece to the EU in 1981. This CAP support has helped to maintain the cultivated area despite the high volatility of the global price of this commodity while linking it to stringent environmental standards, leading to low competitiveness at global level.

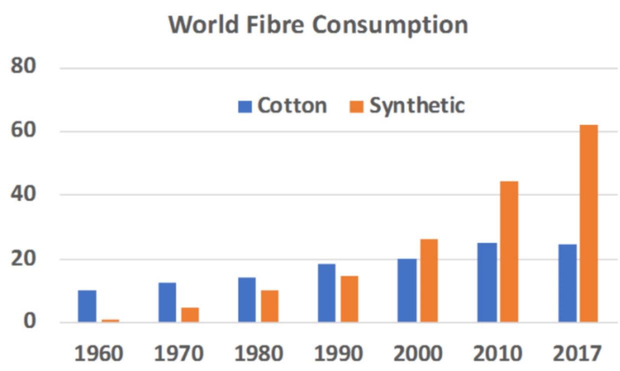

Figure 11. Cultivation area of cotton at world level

The social relevance of this crop is very high in the mentioned countries, in Spain and Greece this crop constitutes one of the main income sources in high unemployment areas of the country. Its production is normally done in small farms; this explains the political relevance that this crop has as the main income source for many families in these regions [24]. Despite this social added value, cotton growers do not have the capacity to differentiate their production since most of it is directly sold at global commodity prices to third countries, mostly Turkey in the case of Greece. This also explains the strong dependency on CAP support of this specific crop.

The organic value chain, a booming market for cotton farmers

The rising of the awareness on the environmental problems related to fiber production and the textile industry has pushed the growth of the demand for organic cotton.

Considering the growing organic demand, there is scope for EU cotton growers to improve sustainability and add value to their product by placing them in fast-growing markets. Even with minor yields, the organic premium perceived by the cotton grower could represent an interesting incentive for cotton growers to convert their production methods.

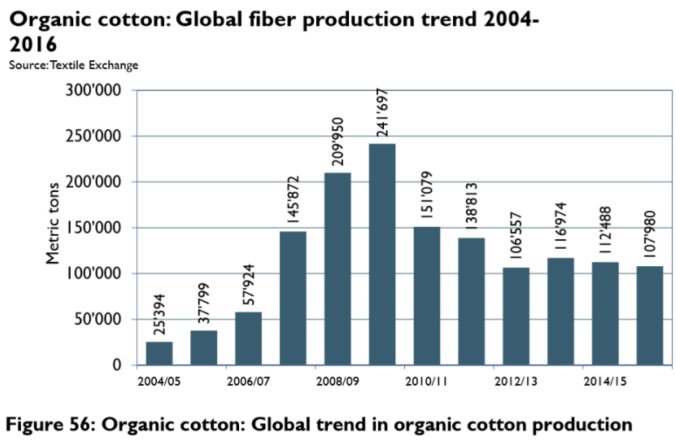

Figure 12. Global fiber production (2004-16) of organic cotton

A quite interest project for cotton value chain with acronym **ECOFIBRA** is taking place in Spain. In this project the textile producers are looking for sourcing sustainable and local cotton in the EU. Spain accounts for 22% of the total EU surface dedicated to this crop with 74.000 hectares. Despite this relevant surface dedicated to this historical industrial crop, the Spanish producers do not manage to differentiate their production and most of it is sold at global commodity prices to Pakistan. The project ECOFIBRA started as an initiative of textile producers located in Catalunya, the textile region of the country, where a group of companies working on organic and sustainable cotton developed this initiative to support the development of sustainable practices in the Spanish cotton growers, located in the region of Andalusia and also boost the sourcing of local cotton for the textile industry. This project shows the potential that the demand for sustainable and organic cotton might have in the development of sustainable practices in the Spanish cotton growers.

6.2 Industrial hemp value chain

Hemp is an annual spring crop that traditional used to be cultivated for its fiber stems. It is a rapid growing crop that can reach a height of 4 m in 100 days (Figure 14). Three main sections can be distinguished in the stems; the bark where the fibres bundles can be found, the woody core body and a hollow space in the middle of the stem. It has a strong tap root system, reaching 1.5-2 m deep into the soil. The main root mass is located 20-40 cm soil depth. Hemp seeds have a spherical-oval shape slightly flattened from both sides, gray-green with a characteristic, marble-like pattern on the shell.

It is originated from middle Asia from where it migrated to Eastern and Southern Asia. It has been first grown in China (5000 years ago) and from there it was spread to the whole world [25]. Hemp is considered as an old-new crop. The last years an increasing interest for industrial hemp has been recorded worldwide[7]. In particular in Europe the area of its cultivation from 14,000 ha in 2012 came up to 42500 in 2017. Although, the main producer in Europe is still France an increasing growing area has been recorded in Italy, Netherlands, Lithuania, Estonia, Ukraine, Romania and Germany. Research on industrial hemp has been carried out in several EU research projects namely HEMPSYS, **4FCROPS**, **Crops2Industry**, **MULTIHEMP** and **FIBRA**. Currently, the crop is being included in **GRACE** and **MAGIC** projects. In the last two cases the crop is being cultivated on marginal and contaminated lands.

Hemp is naturally dioecious crops with male and female plants. The male plants are shorter with higher fiber content [26] that mature earlier than the taller female plants that produced more in terms of seeds. Currently, a number of monoecious varieties have been selected in order the agronomic problems related to the sexual vegetative dimorphism present in dioecious varieties to be reduced. The monoecious varieties produce uniform plantations and the plants have similar maturity, height, fiber content and seed productivity and ultimately efficient mechanical harvest [27]. Currently a total number of sixty-eight varieties [28] are being registered in the European catalogue and cultivated either for fibers, for seeds or for both.

Figure 14. View of hemp (Futura 75) at several stages of growth (source: CRES); a week from sowing, four weeks from sowing, vegetative phase, flowering phase and top of the stems.

Hemp grows best on fertile soils with 7.1-7.6. It should not be grown on acid soils where pH is below 6.0. Hemp has no special requirements in terms of the preceding crop. It grows well after root crops grown on manure and legume crops. It can be even grown for few years on the same field. It improves the structure of the soil due to it tap root. Hemp absorbs heavy metals such as Cd, Pb, Zn, Cu, and thus contribute to the cultivation of contaminated soils. It requires a mild, temperate climate and an annual rainfall or irrigation of at least 500 to 700 mm. The hemp plant is sensitive to short day length which induces early flowering. Flowering time is a very important factor in hemp yield determination, both in terms of quantity and quality. It requires long days (14-16 hours) during its vegetative phase.

[7] www.eiha.org

Hemp can also suffer from fungi, the diseases like Fusarium wilt, septoriosis and gray mildew are found especially in weather conditions promoting these diseases. Sometimes, especially if hemp is grown several times on the same stand, in may suffer from a parasitic plant – branched broomrape (*Orobranche ramosa* L.). Also virus diseases may sometimes attack hemp.

It can be sown when the average air temperature stabilizes at 8-10ºC. The sowing density is strongly depends on the end-use of the crop. Thus, for fibre production 60-70 kg seeds/ha should be applied, while for seeds production this is much smaller (10-15 kg seeds/ha). The row spacing should be 12.5-25 cm or 50-70 cm, respectively. The seeds should be sown 3-4 cm deep. When it is grown for seeds special attention should be given to weed control; especially to *Elymus repens* (L.) Gould. When it is grown for fibre production at high densities and narrow row spacing no special weed control is needed since the crop compete successfully the weeds. The soil bed preparation should be similar to spring cereals.

The optimum fertilizers doses are: N: 90-120 kg/ha, P_2O_5: 70-100 kg/ha, K_2O: 150-180 kg/ha. When the crop it is grown for fibre special attention should be given on potassium and calcium (important for plant cell formation), while when growing for seeds the phosphorus availability is very critical for the seeds formation. For fibre production the NPK ratio should be 1:0.7:1.5, while for seed production should be 1:0.8:1. When hemp follows legumes less nitrogen fertilization is needed. High nitrogen fertilization can prolong the vegetative phase and the risk for lodging is increasing. It grows best when supplied with moisture throughout its growing season and especially during the first six weeks of growth. For optimum yields, 250 to 300 mm of moisture during the vegetative growing stage is required. Droughts at germination and flowering phases can seriously damage the growth and yields of the crop.

In Europe the mean yields in terms of dry stems is 7.5 t/ha and for fibres 2.5 t/ha. The seeds contain 32.5% oil, 70% is corresponding to polyunsaturated fatty acids.

Time of harvesting depends on the purpose of cultivation of hemp. When it is grown for fibre the harvesting

Figure 15. View of harvesting in Romania (source: CREA)

should be done in the beginning of flowering. At that time the fibre are delicate and quite strong and are appropriate to textile production. When the harvesting is being delayed the fiber yields are increasing but because the lignification is also increased the fibres are not appropriate for the textiles but can be used for pulp production. When it is grown for seeds or fibres and seeds the crop should be harvesting at harvested at full maturity phase, when seeds in the middle part of panicle are mature. At that time the fibres can be used for non-textile applications (insulation mats, etc.). In Figure 15 the harvesting of hemp for both seeds and fibres in Romania is presented.

Although industrial hemp is considered as fiber crop, high-value bio-products can be produced from all plant parts (stems, leaves, seeds and flowers) and thus it is considered a natural biorefinery. In Figure 16 presented the current main uses of the crop per plant part. The fibres of its stem are being used for paper and pulp, insulation mats, bio-composites and textiles. The shivs (the woody part of its stem) are being used as construction material, for animal bedding, garden mulch, etc. The seeds can be consumed as food and/or feed, the seeds oil can be used either for food and feed consumption or for cosmetics and heath care products. The flowers have numerous pharmaceutical uses from THC, CBD and other cannabinoids. Finally, from its leaves are being produced pharmaceutical products, tea bags, etc.

Hemp has a very long history of medicinal use. It has been traditionally used by different cultures in treatment of various types of ailments: asthma, cystitis, diarrhea, dysentery, gonorrhea, gout, epilepsy, malaria, fevers etc. The whole plant is considered to be anodyne, anti-inflammatory, antispasmodic, cholagogue, diuretic, emollient, hypnotic, hypotensive, laxative, narcotic, ophthalmic and sedative. Today, hemp is used for relieving side effects of cancer treatments, such as nausea and vomiting. Since it increases the desire for food, it is also used in treatment of anorexia nervosa. It can be used as food component and for production of technical products such as: detergents, varnishes, paints, lamp fuel or an emulsifying medium in pharmacy. Hempseed oil is described as desired raw material for production of so called greasy soap (grey soap). This soap is called also green soap in many counties from the colour given to it by chlorophyll contained in the soap. It is worth mentioning that hemp essential oil, a different substance extracted from hemp is used for a medium repelling parasites found e. g. on horse skin. It also displays properties similar to many other essential oils – bacteriostatic, repellent to pests.

In the figure is presented a value chain for industrial hemp (insulation material from industrial hemp).

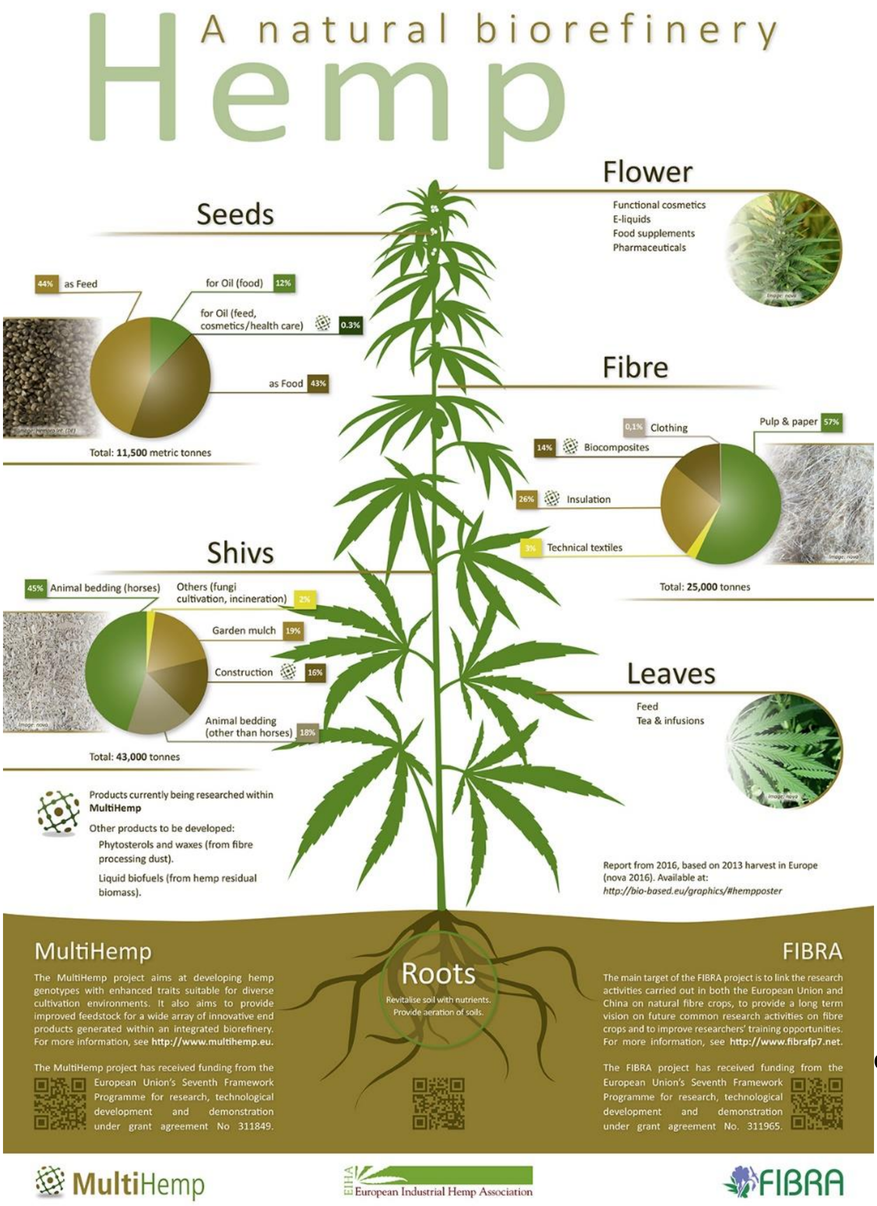

Figure 16. Industrial hemp a natural bio-refinery (developed by projects MULTIHEMP & FIBRA)

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7. Research needs

Problem	Need for research/knowledge gap	Comments
Very few industrial crop options in certain countries. No current experience / trials / advocacy.	Work on new opportunities - with necessary adaptions (varieties, agronomics / disease tolerances) largely focused on other EU countries. Experiences / value chains.	Particularly research with farmers / research / industry.

8. Conclusions and recommendations

Establishment of a bio-based economy has been recognised as one of the key issues for sustainable development. For future developments, renewable resources will play a key role as CO_2 neutral raw material for sustainable industrial production to curb depletion of fossil resources. For each scenario, an integrated chain approach is essential. All aspects need to be addressed from food security, food safety, 'green' energy production and development of sustainable non-food products for industry, to waste management, recycling and disposal. The emerging strategies require combined efforts from both science and commercial enterprise, facilitated by governmental legislation and should be based upon a broad public support.

Problem from Practice	Need for research/knowledge gap	Comments
Networking (Farmers - Agronomist - Industry), bridging the gap, training practice and sharing knowhow about growing industrial crops	Framework for better cooperation between all parts. Track & Trace (Origins, short supply chains, local value adding, etc.). Networking, Database, IP-Transfer. Research & Development Support. Scale up on the field.	There should be a form of providing subsidies and financing in connection with the degree of cooperation Farmers associations/cooperatives, better involvement of consumers on the benefits of the end products, policies, municipalities, processing units, distributors, investors, legislators, researchers. Common regulations (EU wide), specified by local needs
Not enough market	Developing new material	It will allow to have more product on the market Miscanthus has been used in starch based biopolymers as a reinforcement to investigate the impact performance of biocomposites. Incorporating Miscanthus fibres into Novamont Mater-Bi improves the impact performance of the polymer, and this effect indicates a lack of bonding between the fibre and the matrix.

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EIP-AGRI Focus Group
Sustainable industrial crops

MINI PAPER 3: Market opportunities for multi-purpose crops in the EU: a promise of growth, jobs and sustainability in rural areas

JANUARY 2021

Authors

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Table of contents

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1. Summary

This paper aims at highlighting the market potential of multipurpose industrial crops, in the view of steering the creation of sustainable value chains in rural areas capable of delivering a wide range of products, spanning from food and feed to raw material for manufactured industrial goods.

In the view of bridging the knowledge gap of farmers, manufacturing industry and consumers, a set of best practices and possible solutions are presented, as well as the case studies of hemp and poplar.

This document is the result of the contributions of the many different experts that took part to the Focus Group 40 “Sustainable industrial crops in Europe”.

2. Introduction

A more **holistic approach** is fundamental for addressing contemporary policy issues and understanding the complex network of casual links between different spheres. From this perspective, **farmers** shall not only be seen through the prism of **food security and food quality**, but also as providers of **ecosystem services** (preservation of biodiversity, saving of materials and natural resources, increase of soil fertility and carbon capture, promotion of closed cycles of production, etc.) and producers of **raw materials** for the decarbonization of the manufacturing industry. Multipurpose crops can become a valuable asset for helping farmers fulfil this role.

Indeed, multipurpose crops are plants and trees that provide raw materials for processing into non-food products while being used at the same time for food/feed purposes and delivering ecosystem services. By **maximising the utilisation of land,** multipurpose crops help farmers increase their income while **differentiating** their **market outputs**. If coupled with subsidies or other market measures aimed at rewarding sustainable practices, the exploitation of multipurpose crops could eventually result in a **greater security for farmers** in the value chain and in fairer retributions.

International markets are ready to shift towards more sustainable goods and services, therefore compensatory measures such as carbon farming for credits may further incentivise an increase in demand. A meaningful **prospection of market opportunities**, an attentive analysis of the barriers and bottlenecks, and the **dissemination of best practices and policy guidelines** are the three enabling conditions for ensuring a swift transition of our economies, as well as the aim of this paper.

3. Market opportunities

3.1 The economic and environmental interest of growing multipurpose crops

With a growing global population and the increasing degradation of ecosystems, the **maximization of land and resources** must become a top priority for our societies. This rationalization needs to be done in accordance with natural constraints through the perspective of re-establishing a **healthy status of our natural environment** and **mitigating the impact of extreme weather events.** Multipurpose industrial crops represent a valuable tool for achieving the aforementioned objectives as they can deliver different products on the same land parcel, most often providing in parallel positive environmental externalities.

Used as an alternative raw material for manufactured goods, multipurpose industrial crops are indeed a perfect resource for **decarbonizing industry** and has the potential to give a green impetus to the **growth of rural areas**, through the **re-localisation of essential manufacturing** industries (textile, pharmaceutical, feed, bio-based composites, etc.), the **creation of innovative value chains** (graphene,

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new materials, etc.) and the valorisation/conversion of existing ones (food, packaging, downstream industries, etc.).

Creating new opportunities in the EU rural regions is even more fundamental, taking into account declining real commodity prices, the reduction in government subsidies and increased environmental regulations, which all undermine the long-term competitiveness of EU agriculture. New uses for existing crops and/or new value-added crops could be proposed to diversify **EU agriculture and supporting the economies of rural areas**.

An attentive mapping of the needs of national and local economies is essential for creating a fully functional and efficient chain of production for industrial crops at **a sustainable scale and deeply integrated at the EU level**.

The efficient management of the value chain also needs to ensure a **full circularity**. For this purpose, particular attention should be given to the product design and the valorisation of waste material. This is not only an environmental requirement but a profitable economic choice. For example, efficient utilization and recycling of residual biomass regenerated from the medicinal and aromatic plants sector have had an immense impact on economic growth, environmental sustainability and social benefits. Effective recycling of these residual biomasses could be a source of extra income for the aromatic plants' growers (viz. compost, biochar, biogas, enzymes, bio pesticides, etc.). Thus, dual utilization of distillation biomass not only reduces the cost of finished product but also solves the problem of disposal of this huge biomass.

3.2. Opportunities for sustainable farming

In terms of farming methods, new and more sustainable practices seem to be particularly applicable to multipurpose industrial crops. These include **organic farming** and **agroecology**, which are still small compared to traditional farming but enjoy great popularity among consumers: between 2009 and 2018, the value of the EU's organic market more than doubled (IFOAM). Consumers' considerations start going beyond the farming methods and purchases are more and more influenced by the need to reduce environmental damage through recycling and purchasing ecologically sound products (Paladino and Baggiere, 2008).

Sustainable farming practices seem to be particularly interesting if we take a look at the price evolution of agricultural commodities. European farmers are facing several challenges in order to operate in an open global competitive market economy. Many of the traditional markets and channels where farmers were selling their goods are facing strong variability in prices producing seasonal crises where agricultural prices fail to cover production costs. This current market trend is also affecting agricultural products with non-food uses, from biomass for energy to fibre for textiles many global markets are exposed to increased volatility.

One of the exceptions to this unfavourable tendency that can be observed in international agricultural markets is the organic sector. This subsector still represents a small share of EU agriculture, specifically 7,7% of the EU agricultural land (Willer, H. et al 2020). However, this is far from representing a niche market, furthermore it is growing steadily in almost all EU countries. When observing the organic market, retail sales show an even more dynamic picture: with almost 20 years of continuous growth including growth rates of double digits in the last few years this market is becoming one of the biggest forces in EU agriculture. This strong tendency in the demand for organic agricultural goods is growing faster than the ability of farmers to respond to the demand. Furthermore, this market is attracting new actors which has had an impact on the products demanded, an increasing number of industrial actors are investing in organic related products, from textile to cosmetics, which is providing many new market opportunities for industrial crops.

In addition, recently the EU has published the strategy "Farm to Fork" setting ambitious environmental objectives for EU farmers to be achieved by 2030. This strategy has a strong focus on food production and consumption, however the objectives established are related to the whole of EU agriculture. In this context,

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the EU surfaces dedicated to industrial crops is not excluded from achieving these objectives, for example, reaching the target of 25% organic agricultural land by 2030. This political framework is also preparing the ground for a needed transition where industrial crops need to play a role.

3.3. Trends and market opportunities

Multipurpose crops can play a key role in the transformation of EU agriculture. The development of the bioeconomy is creating new market opportunities for agricultural goods and their by-products: what was once considered waste is now considered a new resource. Several farming by-products can represent essential raw materials or ingredients for the adequate actors, from feed to fibre there are many new opportunities for revalorizing these by-products. This can also be applied to organic farms where the growing demand can increase the premium income that organic farmers receive for their production.

Bioenergy and Biofuels

Industrial crops can be used also for the production of biofuels and bioenergy, capable of **replacing fossil energy**, with demonstrated benefits in mitigating climate change. These crops can be used as a sustainable source of energy, providing heat, gas and fuel to produce heat, electricity, and transport fuels. In the production of biofuels and bioenergy, combustion, gasification, pyrolysis, fermentation and torrefaction processes, among others, can be used. Some of these technologies are available on the market, e.g. biomethane, district heating networks, biomass to generate electricity and different 1st generation transport fuels (ethanol, biodiesel) - while other technologies still need additional support to penetrate on the market (gasification, pyrolysis and ethanol from the lignocellulosic raw material). However, in the "cascading use" of biomass, many experts and policy makers recommend a hierarchical sequence prioritizing the uses of greater value first, relegating the use of energy to the last. In this way, higher added value and greater benefits from carbon sequestration are achieved. (Schmidt et al., 2015; von Cossel et al., 2019). The produced bioenergy and biofuels by the different processes can have different market opportunities. Heat is commonly produced by combustion of lignocellulosic biomass, mainly woody biomass, in boilers, furnaces or stoves. The residential sector uses heat for domestic space heating and hot water in houses with small-scale devices that can use wood logs, pellets and wood chips. Employment of wood chips in medium and large scale devices, including combined heat and power (CHP), provides heat to district heating, being the main users buildings and industry. The technology is commercially available and there is already a relevant market. Industrial crops can be also used to produce power/CHP from combustion of solid biomass or from gaseous or liquid biomass. Typically employed gaseous and liquids fuels are biogas from digestion or gas from biomass gasification, as also biodiesel. All these technologies are already commercially available but only power/CHP linked to combustion and digestion have a relevant market. Production of biofuels, liquid or gaseous, from industrial crops is another market driven opportunity. These biofuels can be employed for road transportation (e.g. biodiesel, bioethanol), which is already commercially available and with a relevant market, or to other applications. The current regulations limit first generation biofuels (produced from food crops), while promoting second (produced from lignocellulosic biomass or waste) and third generation (from algae) biofuels, to avoid competition with food crops.). Production of advanced liquid biofuels, methane, hydrogen, torrefied biomass and solid biochar are being studied and some of the processes, e.g. the gasification though Fischer-Tropsch synthesis, are already at the demonstration level, or at commercial stage, e.g. biomethane. Future developments should achieve a high technical reliability with low costs while reducing CO_2 emissions.

Plant Chemistry

Fossil hydrocarbons, which currently represent the basis of organic chemistry, can increasingly be replaced by chemicals from the biological platform. Chemicals based on biogenic carbon, which can originate from a variety of raw materials, including different industrial crops, play a key role in the bioeconomy. Currently, in the European Union (EU), this is one of the most promising sectors, focusing on the search for equivalent alternatives. Oilseeds, as a source of fatty acids, can feed the European chemical industry for the production of plastics, surfactants, detergents, lubricants, plasticizers, paints and other products. An integrated and economical cascade biorefinery system to refine the sugar beet pulp allows to isolate high value products for detergents, products for personal care, paints and coatings and composites. The production of monoethylene glycol from sugar fermentation can be added to other components in the production of bio-polyethylene terephthalate (bPET), which, in the long run, can replace fossil-based PET. The resin acids found in tree resins can be used in different applications, namely paints, lacquers, varnishes, soaps, and can replace synthetic acids, such as 2-ethylhexanoic acid or naphthenic acids derived from petroleum.

Industrial crops (e.g. lignocellulosic crops) also represent a source of lignin. Currently, lignin is almost exclusively used to generate energy, however, in view of the enormous potential from the chemical point of view, it can contribute to the expansion of the forestry industry to the emerging bioeconomy. Lignin is one of the most abundant polymers in nature, containing a high number of aromatic compounds, so, due to its structure and chemical properties, it can be used in the production of a wide variety of chemicals, especially aromatic compounds. In this way, lignin can be considered an excellent resource in obtaining bio-based products, having a very promising potential. Despite potentially being an excellent opportunity in the production of aromatic monomers and polymers, lignin is still underutilized, mainly due to the difficulty in obtaining pure aromatic chemicals. Thus, new technological developments are needed to break down the chemical structure of lignin into basic chemical products such as benzene, toluene, xylene, phenols, hydroxybenzoic acids, as well as coniferyl compounds, sinapyl and p-coumaryl. Lignin is also a valuable source of other products, such as, for example, carbon fibres, which present less environmental impact than traditional carbon fibres.

FOOD SUPPLEMENTS, PHARMACEUTICALS AND COSMETICS

In the past decade, we have seen a rising interest of consumers towards the use of phytocompounds as food supplements, in pharmaceutical or in cosmetic preparations. The market opportunities ahead will probably continue to grow as more and more people turn from synthetic compounds to natural products.

Many industrial crops, such as oilseed cops, rich in phytocompounds, are a source of different chemicals that can be used by several industries operating in the health domain. Fatty acids, terpenes, terpenoids, flavonoids, cannabinoids, isoflavones, phenolic substances and lipids can be easily extracted from nature, refined and used for a wide array of products (Pascoal et al., 2015; Barbosa et al., 2020; Maurício et al., 2020).

A growing demand of medicinal and aromatic plants (MAPs) is observed. In case of aromatic plants, the market always has been stable, with an important consumption in the food sector (seasonings, drinks, etc.). In case of the medicinal plants, the herbalist market seems to increase due to attitude change of consumers towards natural products, and due to changing healing tendencies influenced by scientific studies. On the other hand, the EOs market is supported by the diversity of products, the great number of users (increased with the food aromatisation with natural flavours) and the international trading aspect. The interest in developing cultivations in is supported by the fact that many industries have import problems of raw material supply in quality and quantity (Moré et al., 2005).

This could be a good entry point for growers in the EU to grow high quality MAP. The EIP-AGRI Focus Group on medicinal plants completed in 2019 provides interesting inspiring examples (**https://ec.europa.eu/eip/agriculture/en/publications/eip-agri-focus-group-plant-based-medicinal-and**).

PLANT PROTECTION PRODUCTS

There is a large demand in the organic agriculture sector for natural pesticides, and in the developed economies this is a promising, expanding market. The total demand for biopesticides doubled in the last decade, highlighting a clear growing trend for any type of eco-friendly product.

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Concerns over the potential impact of pesticides on the environment has now become more pressing and more stringent pesticide registration procedures (EU Green Deal) have been introduced. These new regulations intend to reduced the number of synthetic pesticides available in agriculture.

Some essential oils have shown some potential as herbicides. They act as non-selective, contact herbicides (burn down) that can provide good but transient weed control. Good examples of essential oils for weed control are pine, lemongrass, citronella and oregano (Clay et al., 2005; Scarfato et al., 2007; Vasilakoglu et al., 2007; Young, 2004;).

Recent reports indicate that the use of natural product and natural product-derived insecticides continue to increase, whereas sales of organophosphates are declining. The same for fungicides. Neem-based products and essential oils of Rosemary and thyme are constituints of some potential products due to their good effects agains insects and fungi (Isman, 2006; Karl-Heinz, 2002; Walivitiva et al., 1998).

COLORANTS AND DYES

Chemistry is looking more and more to plant-based solutions. This industry will face several challenges. It will have to reduce its dependence on petroleum. One of the solutions is the use of biobase molecules/extract. It will be a challenge as it used to copy vegetables/plant.

Natural dyes, obtained from plants, insects/animals and minerals, are renewable and sustainable bioresource products with mínimum environmental impact and known since antiquity for their use, not only in coloration of textiles (Kadolph, 2008) but also as food ingredients (Dweck, 2002) and cosmetics (Frick, 2003). Biomordant sources are either plants with high tannin content (Prabhu and Teli, 2011) or metal hyperaccumulating plants (Cunningham et al., 2011). Recently chlorophyll extracted from different plant sources has also been successfully employed as biomordant (Guesmi et al., 2012a,b). Vegetable tannins are water soluble polyphenolic compounds found in wide variety of plant parts such as bark wood, fruit, fruit pods, leaves, roots and plant as listed in Shahid et al. (2013)

Agromaterials

BIO-BASED POLYMERS AND NATURAL RUBBER

Bio-based polymers were the first to be used in history for making plastics. The first polymer was derived from cellulose and used as film for cameras or glue for the wings of airplanes. Their use has declined with the discovery of petroleum (less expensive and easier to process).

Bio-based polymers, often called "bio-based plastics", have a high potential as a substitute for fossil resources thanks to their physical properties and many areas of application. The characteristics of biopolymers allow faster decomposition. Examples of biopolymers are starch, PLA (polylacticacid) and PHB (polyhydroxybutyrate). PLA and PHB can be produced by the action of bacteria that use a carbon source for synthesis, normally consisting of sugars from corn, potato and sugar cane residues. Studies are underway to allow the production of biopolymers from agro-industrial waste.

Since few years, biomaterials have grown more and more each year. Even if today they still occupy a thin part of the market (less than 1% of plastic are biobased), it increases each year.

Other compounds of biological origin are also being studied to obtain biopolymers, namely pectin, among others. Opuntia spp. is a crop that is expanding in the Mediterranean and that represent a rich source of pectin. Currently, the use of these materials mainly concerns niche markets and special applications, namely, bio-based plastics, for example, with a focus on durability, resistance and degradability. The differentiation of this type of materials through, namely, adequate labelling, is essential for users to clearly recognize the environmental benefits of these products and, even, proceed to deposit this type of waste in the correct container, avoiding contamination of plastic waste that makes it impossible to recycle.

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Natural rubber, one of the most promising and innovative bioproducts within the bioeconomy, is a source of elastomeric polymers suitable for large-scale technical applications, such as tires. The natural elastomer has an exceptional combination of mechanical and physical properties, which make it irreplaceable with synthetic elastomers. Since 2017, natural rubber has been on the list of critical raw materials for Europe and, currently, given the global trend of replacing petroleum products with renewables, they represent the main driving force in the search for potential alternative sources for the production of rubber. As such, there are other plants that are currently being studied as an alternative source of latex for rubber production, namely the guayule and the Russian Dandelion. The guayule has recently been the subject of research due to the fact that its latex is hypoallergenic. Currently, surgical gloves made with guayule latex are already available. In 2015, the Bridgestone Group produced the first tire made from guayule-derived natural rubber. The Bridgestone Group's proprietary technologies were applied to every process in the production of this tire; From guayule cultivation and natural rubber extraction, purification, and evaluation, to tire production and evaluation. Versalis, a Eni's chemical company (Italy) and one of the most important companies in the polymers and elastomers industry, and Bridgestone Americas (Bridgestone), the world's leading producer in the tire industry, signed a strategic partnership agreement to develop and implement a comprehensive technology package to market guayule in agriculture, sustainable rubber and chemicals from renewable sources. New start-up come up on the market to work with guyanol latex like Guatecs SAS.

BIO-BASED COMPOSITES

Fibres from traditional plants such as flax and hemp, among others, as well as from wood, constitute an important area of the bioeconomy. These fibres can be mostly used as building materials, in thermal and / or acoustic insulation materials, in the production of composites, with applications in the automotive industry, packaging, or in construction, among others (Fernando et al., 2015).

Nanocellulose is also a major innovation trend, being produced from cellulose, as it has special properties: high surface, great bonding potential, and high bonding capacity to water. The most outstanding nanocellulose-based materials are hydrogels, aerogels or new composites when mixed with organic polymeric matrices, carbon or graphene nanotubes and inorganic materials. These materials can be applied in several areas and industrial products, such as packaging, flexible electronic products, sensors, in energy recovery systems, liquid crystals, biomedicine and cosmetics, catalysis, adsorption, separation, decontamination, filtration or even as fire retardants. This product has great potential as a highly efficient biodegradable reinforcement for bioplastics, suggesting itself as a potential biological substitute for carbon fibre in technologically advanced compounds. (Pires et al., 2019)

The term "bio-composites" covers the following materials:

- non-biodegradable polymers derived from petroleum, reinforced with biofibres;
- biopolymers reinforced with biofibres (the most environmentally friendly are called "green composites");
- biopolymers reinforced with synthetic fibres, such as glass or carbon and
- inorganic materials containing natural fibres in their composition.

BUILDING MATERIALS

The built environment in the EU is responsible for approximately 40% of EU energy consumption and 36% of the CO_2 emissions. The construction sector accounts for about 50% of all extracted material and is responsible for over 35% of the EU's total waste generation. At present, about 35% of the EU's buildings are over 50 years old and almost 75% of the building stock is energy inefficient. The annual renovation rate of the building stock will need to at least double to reach the EU's energy efficiency and climate objectives (today it varies from 0.4% to 1.2%). In parallel, 50 million consumers struggle to keep their homes adequately warm or cold (European Commission, 2020).

It is clear that the use of low-embodied-carbon bio-based materials is a key tool for the EU has to reduce buildings' carbon footprint while increasing their energy efficiency. Industrial crop can provide a large number of raw materials that can be integrated either to conventional building materials or completely substitute them.

Cork and wood are two very well-known examples used for insulation and structural purposes. Other materials include bear loading hemp bricks, in situ hempcrete casting, prefab straw walls, flax or hemp fibre insulation mats, etc. Although some materials still need technical improvement, some others are already widely used and have even proved superior to conventional products in terms of temperature and humidity regulation.

Fibres for textile

Natural fibres are increasingly being recognized as a better alternative to synthetic fibres, which use unsustainable inputs (fossil or mineral resources), tend to last less and pose problems in terms of microplastics pollution. Although it would be difficult with the current technologies to completely give up on synthetic material in the textile sector, a partial decarbonisation of the sector is practicable. As more and more stringent environmental legislation together with an increased consumer awareness, are the two forces driving the transition which offers high perspectives for natural fibre.

However, the choice of natural fibre is not only due to environmental considerations. Most, if not all, natural fibres have specific qualities often superior to their synthetic alternatives, the price being so far the only factor influencing the demand and supply.

Hemp long fibres, for example, have some unique properties that make them perfectly fit for most uses. They are incredibly resistant and antistatic, transport moisture quickly, absorb heat very well, protect against UV radiation, resist mould and bacteria.

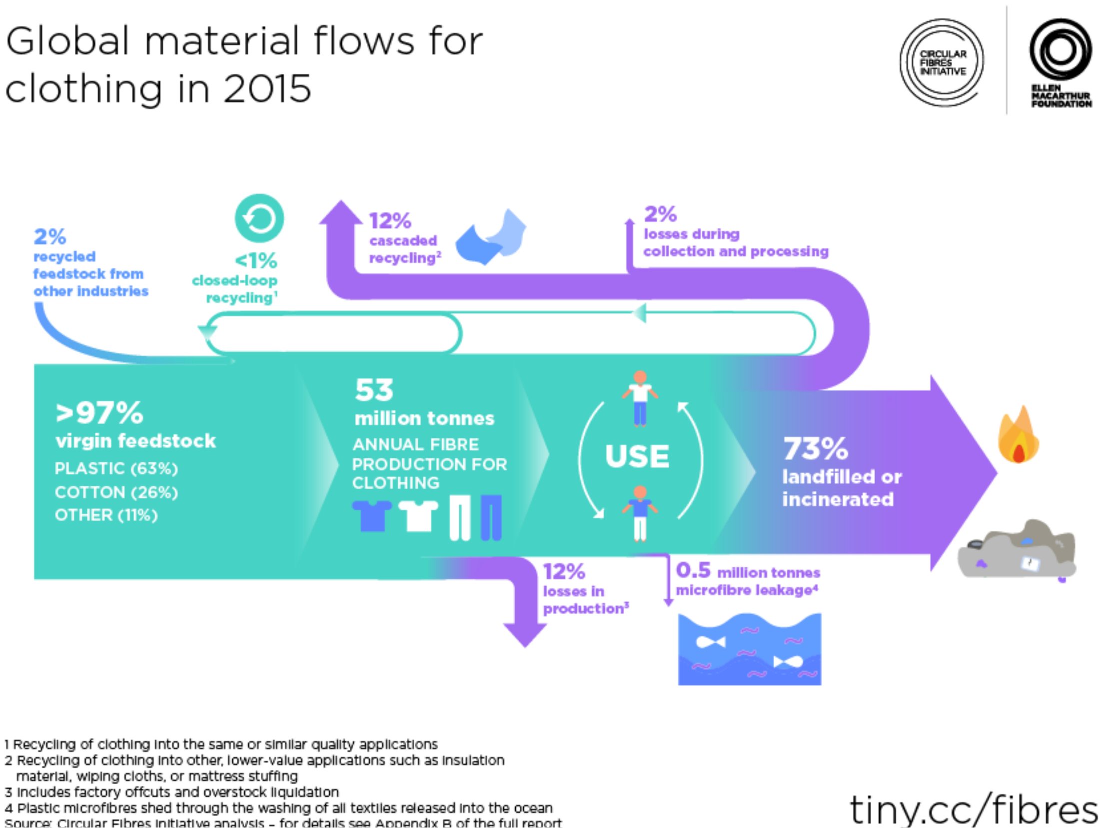

Figure 1. The current production volumes of textile fibres

Looking at the current production volumes of textile fibres, fossil-based synthetic fibres are the largest (65%), followed by cotton (26%) and other fibres (11%). Regenerated fibres only make 2% of the total feedstock (see Figure 1.). Considered the specific difficulties of the global cotton value chain (social issues in third countries, high level of input in conventional agriculture), other natural fibres seem to have a huge potential ahead. This is particularly true for Europe, that is the first single market for textile in the world.

4. Case studies

In the following table, you will find a list of applications for each of the main industrial crops selected by the Focus Group.

4.1. Overview of multipurpose crops

Crop	Energy	Food	Feed	Biochemicals	Raw material
Hemp	Pellets for heat production, biofuel	Seed, Oil, Protein, Fibres, phytocompounds	Bird seeds, meals, Fibres, proteins, phytocompounds	Cannabinoids, terpenes, polyphenols, essential oil	Textile, construction, paper, plastics fillers, oil
Medicinal and aromatic plants	Biomass after distillation for biogas	Super food, herbodietetic	Natural aditives	Biopesticides, Cosmetics,Drugs, Colorants, Perfume	Organic mulching (biomass) (after distillation)
Flax	heat production	Oil, seeds	proteins, meals		Textile, construction, paper, plastics fillers, oil
Camelina	Sustainable biofuels, including biojetfuel (HEFA), HVO and biodiesel	Oil	Meal – high content of quality protein for animal feed. Husks - high content of fibre for animal feed.	Polyphenols, glucosinolates	Oil for biofuels Straw for energy applications or organic matter for soil
Poplar	Wood chips or energy pellets, liquid fuels (bioethanol, biodiesel), pyrolysis oil, gasification gasses	-	Biochar as feed additive, leaves (having higher content of zink) in agroforestry systems	Sugars and lignin, gasification gasses - for all type of chemicals, bioplastics	Textile (lyocell), pulp for paper, construction materials (traditional - lumber and wood panels), and novel - LVL, CLT), furniture
Cotton		Seed oil	Seedcake	Seed oil	Short fibre

4.2. Hemp

Hemp is a **wind pollinated, dioecious and staminate** plant, well adapted to most European conditions. Although it belongs to the same genus as the recreational cannabis, commonly known as 'marijuana', its flowers do not have any psychoactive effects as they contain low levels of the tetrahydrocannabinol. The varieties currently registered in the European Union catalogue have a **THC level below 0,2%,** while in other countries this limit is set within a range of **0,3% and 1%**.

Hemp is harvested for **seeds, fibres, hurds and biomass for extraction** (flowers and leaves). It is subsequently transformed into a wide array of products: food, feed, cosmetics, bio-based plastics, bio-based composites, textile, paper, construction materials, graphene and pellets for energy production.

Hemp has been a traditional **food** source in Europe for centuries. All parts of the plant except stems have been consumed. While seeds are particularly rich in high-quality proteins and have a unique essential fatty acid spectrum, flowers and leaves are rich in precious phytochemicals (cannabinoids, terpenes and polyphenols).

Used as **feed**, hemp has also a very interesting role in animal nutrition and wellbeing. It is consumed as hempcake, hempseed or as extract, but never as the only compound of their diet. The share of hemp green fodder (whole crop), straw, stalks in the total feed consumption of cattle is usually kept below 15%.

Cosmetics products containing Cannabis derivates have been on the EU market for decades. In recent years, these products surged in popularity. Their use has evolved into a major skin care trend with numerous products marketed as oils, balms, creams, lotions, and facial serums. The demand has been driven by recognised and validated properties related to hemp seed oil and hemp extracts.

Hemp-based **construction materials** have an exceptional thermal performance which reduces energy consumption, while sequestering carbon. They include hempcrete (a hemp-lime composite walling and insulation material), as well as hemp wool and fibre-board insulation. Hempcrete is non-flammable, resistant to mould and bacteria, naturally regulates humidity and has an exceptional thermal and acoustic performance.

Because of its high level in cellulose hemp (65-70% higher than wood) is one of several plant based raw materials that can be used for **bio-based plastic** and **paper pulp** production. Also hemp fibers are widely used in both applications and represent a strong and durable raw material easily adaptable to different conditions. Filaments for 3D printing and granules for injection molding are already available and could concur to dramatically reduce the impact of plastic products.

Textile can be made of the long and short fibres and is naturally antibacterial, resistant to UV light, mold and mildew, and extremely durable. Shivs can also be used for extracting cellulose and making lyocell or viscose.

Despite the great potential of this crop, many bottlenecks and hindrances stop hemp from being used more widely. An underlying distrust is still present at different levels, including the public administration, stemming from a lack of knowledge on the differences with marijuana. Furthermore, a clear European legislative framework is still missing, causing major problems of interpretation and attribution of competences.

4.3 Poplar

Poplars are probably one of the most widely used industrial crop and having strong share in traditional markets, but also gaining in novel markets.

They range from **sawn timber to veneer, plywood and composites as wood-based products, wood based panels (particleboard, OSB, fiberboard), as well as pulp and paper** as fibre-based products. The primary wood products, in turn, can be used in many construction applications, as well as for containers and furniture. In addition, several new technologies and new alternative uses for poplar wood have emerged globally, especially in the **engineered wood composites** sector (e.g. LSL, LVL, I-joists, CLT) and **wood-plastic composites**.

EU supplies from planted poplar forests/plantations ranges about 5 million cub m/year. France, Italy and Spain are the major users of poplar wood in the EU in traditional industries: pulp production, sawn timber, veneer, and wood based panels.

Chemicals and energy may also be produced from poplars. Energy plantations of poplars (short rotation crop, SRC) are primary established in Poland, Hungary, Romania, Germany, UK. And the primary market of these plantations are energy chips and energy pellets.

As agricultural crop, grown as SRC at high density and 2-3 year rotations, poplars traditionally have been targeting energy market – supplying chips to local biomass boilers for heat production. Recently in the EU the trend towards longer rotation of poplars can be observed as more poplars grown on agricultural land are being used for higher value industrial purposes to supplement wood from traditional forests: pulp and paper production, wood based panels, sawn timber. Despite huge energy market, this shift from energy market towards higher value added products is happening due to very unstable energy prices and high risk associated with falling oil prices.

Due to their chemical structure (high cellulose and chemicellulose content and lower lignin content) poplars are perfectly suited for **liquid fuel (bioethanol** at Versalis, former Chemtex, biorefinery**), various chemicals and bio-based plastics** production from extracted sugars, the market of which is relatively unlimited.

Recently poplars are also gaining market share in **textile** industry. Lyocell is mostly eucalyptus based, though oak, birch are being used and poplar fibres can be mixed as well. Lyocell can have many different textures, but the basic fabric is soft to the touch. It is hypoallergenic and doesn't cling, it is also 50% more absorbent than cotton. The wold market share of Lyocell is estimated at 1 billion EUR and steadily grows.

Poplars also are used in biochar production, which is used as soil improver, absorber or feed additive.

Poplars are well established in various markets as the provide the same material as from traditional forests, but the major advantage of poplars is that they can be produced in relatively short rotation times to produce maximum yields of fibre on a sustainable basis. With this rapid growth and biomass accumulation very significant volumes of CO_2 are being sequestrated in poplars, especially grown at longer rotations.

Future poplar utilization should be based on an integrated and total use concept, i.e. produce the highest-value products or product combinations from a given raw material input, so that nothing is wasted. Future growth in poplar utilization will most likely come in the area of composite products for existing and new applications, and in bioenergy (liquid fuels) and chemicals. Stable investment in appropriate research, development and innovation and further international cooperation will advance poplar utilization for the benefit of society.

5. Existing good practices and possible solutions

5.1 Biorefineries

Industrial crops research has been funded by the European Union since the beginning of the EU Research Framework Programme. A large number of research projects have been conducted in order to explore the potentialities of many new crops for the production of bio-based materials and bio energies.

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Following the investments in research, in Italy for instance, some big industrial groups invested in production of fibre (Gruppo Armani), energies (Chemtex for Bioethanol, about 400 biogas plants installed, about 10 power generation plants and thousands of heat unit feed with energy crops) and biorefineries.

The case study of the Matrica Biorefinery, in Porto Torres (Sardinia), as CREA carried out research activities in order to develop the integrated supply chain related to one of the industry crops utilized in the process: the cardoon (Cynara Cardunculus) cropped in marginal fields.

Matrica Biorefinery is a 50:50 joint venture between an important company operating in the manufacture and marketing of petrochemical products and a company at the forefront of the bio-based plastics industry. The purpose of the joint venture is to reconvert the petrochemical facility at Porto Torres into a integrated green chemistry complex to develop a state-of-the-art range of products sourced from vegetable raw materials, using an integrated agricultural production chain.

Starting from selected industrial crops with low levels of environmental impact, Matrìca produces a series of innovative intermediates that are deployed in various different industries: bio-based plastics, bio-lubricants, home and personal care products, plant protection, additives for the rubber and plastics industry, and food fragrances.

The logistic system developed was focused on the separated collection in the field of the 3 main products obtainable, seeds, pappus and lignocellulosic biomass, in order to have 3 separated supply chains for the different bio-based products obtainable.

Prototypes harvesters were developed and now 400 ha are cropped with cardoon, harvested by commercial machineries developed by the prototypes.

Other industrial oleaginous dryland crops cultivated in marginal land in Sardinia are evaluated for potential industrial applications. The cultivation techniques and the logistic chains are developed in order to reduce the production cost and the environmental impact taking in account the marginality of the fields.

Several bio-based products are now manufactured in Porto Torres, Sardinia. Vegetable origin bio-based products are made with feedstock from vegetable, used in a variety of fields: biopolymers and plasticizers, biofibers, biolubricants, cosmetic, personal care, plant protection, additives for cleaning and for rubber industry.

Various types of biopolymers are commercialized, which are suited to the processing technologies used for traditional plastics: film blowing, casting, extrusion/thermoforming and injection moulding. All are certified by European and international accredited bodies which guarantee their biodegradable and compostable properties (EN 13432).

6. Necessary actions to scale up industrial crops

6.1. Structuring of the value chains

In order to achieve a well-functioning exploitation of industrial crops, public policies should encourage the sector to structure itself at local, national and European level and to establish well-functioning and fair business relations between the different business actors.

The creation of **Producers Organisations** (POs) and Associations of POs would be a first step in this direction and could facilitate the establishment of individual or collective **contractual agreements** between farmers and first processors (possible Operational Group idea).

Interbranch Organisations (IBOs) could also play a major role in helping to ensure fair retributions and an ordered development of the market. Particularly, it shall be explored the possibility of steering **transregional and transborder cooperation** and creating transnational IBOs. Stakeholders organisations, including POs, APOs and IBOs, should be further integrated in the **policymaking** at all levels and connected among them across Europe. This could further help the exchange of market information, innovative solutions and best practices, but also monitoring the market and responding swiftly to disturbances and opportunities, in close collaboration with public authorities.

Funding from CAP and other financial streams are available for the setting up of collective forms of organisations, risk management funds and contractual relations.

6.2. Policy and regulatory instruments

Focus Group experts consider that policy and regulatory instruments are essential for harnessing the opportunities of multi-purpose crops in Europe. The uptake of multipurpose crops farming and transformation is closely linked with the creation of a **European market for bio-based products**. The precondition for its further development is the setting of product and production standards, coupled by hard and soft policy instrument capable of increasing the market size.

Product standards would help facilitating the entry of the new raw materials in the traditional manufacturing lines. They could be set either through EU regulation or via private standards, developed, managed and monitored within the sector and with the help of sectoral organisations.

Hard policy interventions could be translated into the creation of new product standards through **specific regulations** or the revision of the **Ecodesign directive**.

While, soft policy instruments would rather encourage producers and consumers specific behaviours and might encompass:

- The creation of EU-wide **sustainability certification schemes** allowing comparability between similar products and acknowledging the true impact of each production step;
- **Tax cut or financial advantages** for the purchasing of bio-based sustainable products;
- Incentivization of land maximisation, multipurpose crops farming and carbon storage through the **Common Agricultural Policy.**

All regulatory changes shall be in line with the latest scientific literature and the principle of **sound scientific approach** (TFEU art. 114, 3) and aim at ensuring **legal certainty** and **business planning** for the operators.

6.3. Investments

Investments are key for developing modern and efficient value chains. It would be useful to map the needs of the territories and correctly assess the potential of the different production areas, encouraging trans-border cooperation. Sustainable finance instruments should be updated for encouraging investments in multipurpose industrial crops for decarbonization of manufacturing industry.

Public-private partnerships should be encouraged to easily scale up relevant projects into marketable solutions. Private and public investments should be directed primarily towards **processing lines** that are currently missing on the EU territory (for example hemp fibre spinning or miscanthus/willow processing for energy production), **mechanisation of farming** and **digitalisation**.

Further investment needs include the creation of modern **tracing systems**, facilitations for the **assignment of intellectual property rights**, and of course **research and development**. A **mapping** of further specific needs is probably needed to better adapt the investment policy to the specific realities of European territories and the different value chains.

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6.4 Market confidence

One of the main barriers to the spread of multipurpose crops as viable business model is the lack of market confidence, which refrains investments and slows down innovation. This situation is greatly influenced by a **deficit of information** across the value chain regarding the possibilities offered by these crops, the technologies needed for harnessing their potential and the business contacts.

Networking and matchmaking activities are key for breaking silos and stimulating the take up of new concepts and solutions. Trade platforms could facilitate the access to raw materials, technologies and business partners across Europe in the most efficient way. This would help particularly tackling the lack of processing facilities to process energy crops such as willow and miscanthus, as well as spinning facilities for hemp fibres. It could also facilitate contacts among farmers in need for shared machineries or services, hence incentivise cooperation.

Acquisition of **market knowledge** is also necessary, as it allows businesses to plan forward and better adapt their production to the demand.

Data collection systems based on the principle of **market transparency** need to be put in place as well as communication tools that give the opportunity to all actors to access information, hence equal opportunities. Data shall be harmonised, of high quality and publicly available. **Market analysis** tools should be established, possibly in the form of a Market Observatory organised at European level and fed by contributions from farmers, processors and traders.

Occasions for **exchanges between business operators and Institutions** should be created either informally (conferences, networking, online matchmaking, etc.) or formally (civil dialogue groups, interinstitutional task forces, etc.). They should aim at nurturing a democratic debate, an efficient policymaking and a transparent communication towards operators.

The dissemination efforts can be coupled by **advisory services**, particular support to farmers and SMEs in the spirit of ensuring equity. **Training** needs should also be assessed and tackled via dedicated programs (Erasmus + synergies). Finally, in order to build consumers' trust and further steer the sustainability of products, **traceability systems** should be introduced, relying on the latest technologies and capable of translating to the market reliable information regarding product quality and environmental footprint.

6.5 Sustainability

Specific considerations need to be made regarding the sustainability aspects. **Short supply chains** should be favoured through structuring in **local/regional clusters** and integrated whenever possible to the existing economic systems, steering complementarity and subsidiarity. **Intra-EU trade** should not be hampered by barriers as it favours product innovation and overcomes to possible shortages or market disruptions, hence increasing the resilience of the operators.

Sustainability standards should be established for the raw material production and all the subsequent transformation steps, in partnership with the operators and the scientific community. To this purpose, an overview on the existing standards, either private or national, should be conducted. A particular attention shall be given to the circularity of the products. **Recyclability and compostability** requirements need to be put in place and aim at a zero-waste policy.

Land use being a major issue, particularly in the context of increasing extreme weather conditions, industrial crops surfaces should not be put in direct competition with food production. Complementarity of crops, soil-enriching farming practices, adaptation to changing market conditions could represent possible tools for maximising land and resources.

Ecosystem services provided by farming of multipurpose crops should be recognised and possibly remunerated or facilitated through payment schemes.

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6.6 Digitalisation

Digital tools are of primary importance for ensuring a future-proof development of new economic models. **Smart farming**, **blockchain** technologies, **artificial intelligence** for mechanical processing should be considered as enablers of future opportunities and as precondition for entering the market. However, IT skills of operators are largely inadequate and technological solutions rarely available on the whole territory of the Union. This is especially true for rural areas, lacking the basic IT infrastructure should fast-speed internet connection. **Funding and advisory services** will be key for ensuring a level playing field for all European businesses.

6.7 Research, Development and Dissemination

EU R&D funding should be directed to further developing the potential of multipurpose industrial crops, as they offer a sustainable and long-term recovery of the EU economy.

It is particularly important that each step of a project development is funded, from the **laboratory research** (high risk/few money) to the **deployment of investment** (few risk/lot of money), scaling up being the most difficult part. Projects should aim at concrete deliveries that can be replicated or adapted.

The exchange of knowledge and best practices is key. Public authorities at national and EU level should promote and coordinate **exchange** occasions should be used to raise awareness among industry leaders, retailers and other stakeholders, at the level that is the closest to the development and production. These occasions should be used to raise awareness among industry leaders, retailers and other stakeholders.

Ideas for projects could focus on:

- The use of essential oils, extracts, oils by the chemical industry to substitute fossil derived products;
- Knowledge development on sustainable options to extract, recover, added value compounds and on the processing to high TRL products;
- Drying methods of biomass adapted to farmers' needs;
- Drafting and regular updating of guidelines for energy crops based on the best available information from agricultural research and advisory networks;
- Establishing good practices and tools for encouraging collaboration among stakeholders from a given value chain;
- Evaluating the status of research in the EU on biomass drying, harvesting, storage and compiling guidelines for Member States;

Varietal research aiming at ensuring increased yields, high product quality, low dependence on inputs, etc.

EU funding should be directed to further developing the potential of multipurpose industrial crops, as they offer a sustainable and long-term recovery of the EU economy.

The setting up of operational groups could also help accelerating the structuring of the value chains. A few proposals are listed below:

Operational Group on **hemp fibre and other natural fibres** > objectives: achieving high quality, low environmental impact and structure (recreate) the EU value chain of fibre/yarn/textile production;

Operational Group on the **setting up of small-scale Biorefineries** > objectives: assess the feasibility of biorefineries on the different territories of the EU, steer the investments, promote the production of the most adapted crop(s) at local scale, establish links with the industry and adapt to the market needs;

Operational Group on **biomass availability** > objectives: matching offer and demand for biomass, focusing on local supply chains integrated at EU level, promoting the use of bio-based raw materials from industrial crops.

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7. Research needs

Use of essential oils, extracts, oils by the chemical industry to substitute fossil derived products	More knowledge on sustainable options to extract, recover, added value compounds and on the processing to high TRL products	
Sustainable standards for cultivation and manufacturing of industrial crops	Overview of existing sustainable standards, networking with the groups who work on them and put scientific research to support those moves.	Create working groups of people who will put together timeline and manage responsibly creation of those needed standards.
Uncertain regulatory framework and regulatory barriers	Sound scientific approach (TFEU art 114, 3.)	Industry needs legal and planning security and science based regulations
Networking (Farmers - Agronomist - Industry), bridging the gap, training practice and sharing knowhow about growing industrial crops	Framework for better cooperation between all parts. Track & Trace (Origins, short supply chains, local value adding, etc.). Networking, Database, IP-Transfer. Research & Development Support. Scale up on the field.	There should be a form of providing subsidies and financing in connection with the degree of cooperation Farmers associations/cooperatives, better involvement of consumers on the benefits of the end products, policies, municipalities, processing units, distributors, investors, legislators, researchers. Common regulations (EU wide), specified by local needs
Development of Biomass Trade Centres to mobilise. At present there is a lack of processing facilities to process energy crops such as willow and miscanthus. Farmers like structures such as market outlets, machinery and infrastructure.	Research on drying methods of biomass needs to be brought to farmers. Much of this work has already been researched in the past. Grower guidelines of energy crops need to be continuously updated with the best available information for agricultural research and advisory networks.	An evaluation of European wide research on biomass drying, harvesting, storage should be compiled and developed into guideline documents for the various member states. The growing of such energy crops could become part of CAP requirements at farm level
Increase land availability for industrial crops without displacing food crops	Develop innovative and sustainable growing schemes that can also provide ecosystem services: ▸ Catch cropping ▸ Relay cropping Intercropping	Developments and optimization of the growing schemes can be come from: ▸ Mechanization ▸ Crops growth cycle (precocity) of main and catch crop Agronomics, including species rotation/association

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8. Conclusions and recommendations

Problem (short description):

Value chains are unstructured and lack product standards. In addition, there is a general knowledge gap among farmers, manufacturers and consumers regarding what can be delivered by multipurpose crops. As a consequence, the scale-up of the supply is difficult to achieve.

Idea (solution, activities):

- Promote the conclusion of fair contracts and agreements between farmers and first processors;
- Encourage cooperation among farmers and structuring of the sector in POs, APOs and IBOs capable of monitoring the market and responding swiftly to disturbances and opportunities;
- Establish modern traceability systems, relying on the latest technologies, need to be put in place in order to better communicate the product quality and sustainability;
- Develop product standards through EU regulations or private labels;
- Enhance the knowledge and best practices dissemination through a correct monitoring of the market at European level (creation of a Market Observatory);
- Continue funding research & development project aiming at ensuring increased yields, high product quality, low dependence on inputs, etc.

Where (country, region): European Union, common market should have common solutions

Who (to involve, should participate):

Farmers, consumers, policymakers, regional and local governments, processors, distributors, investors, researchers.

Problem (short description):

The EU and national Hemp value chains need to be correctly assisted by public policies in their development according to a "whole plant" approach (i.e. the use of fibre, shivs, seeds, flower and leaves).

Idea (solution, activities):

- Legal barriers need to be lifted at European and national level, but most importantly hemp shall be clearly distinguished from high THC varieties (used for adult or medical purposed), hence excluded from the application of the Single Convention on Narcotic Drugs and cleared for harvesting in all its parts (flowers and leaves included);
- Private investments should be encouraged towards processing lines that are currently missing on the EU territory (fibre spinning for example) and mechanisation and digitalisation of farming;
- The sector should be accompanied in its internal structuring at European, national and local level and sectoral aids should be put in place to the benefit of the whole value chain;

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▸ The "whole plant approach" shall be favoured and varietal research needs to be pursued in order to achieve higher product quality and yields; ▸ Local sourcing needs to be encouraged, in order to avoid transportation and to better integrate hemp production within existing value chains (fishery, food processors, textile producers, etc.); ▸ The dissemination of innovative and sustainable processing technologies needs to be accelerated and further research incentivised.
Where (country, region): All EU
Who (to involve, should participate): Farmers, consumers, policymakers, regional and local governments, processors, distributors, investors, researchers.

Problem (short description): Market confidence refrains investments and slows down innovation because of a deficit of information across the value chain.
Idea (solution, activities): ▸ Biomass and bio-based materials trade platforms could facilitate the access to products across Europe in the most efficient way; ▸ Training needs for farmers, industry and other stakeholders should be assessed and tackled via dedicated programs (Erasmus + synergies); ▸ Data collection shall be harmonised in Europe allowing for better quality and availability of data; ▸ Market analysis tools should be established (Market Observatory); ▸ Multi-stakeholder consultation fora should be created either informally (conferences, networking, online matchmaking, etc.) or formally (civil dialogue groups, interinstitutional task forces, etc.
Where (country, region): Europe
Who (to involve, should participate): Farmers, consumers, policymakers, regional and local governments, processors, distributors, investors, researchers, engineers, machine manufacturers, advisory bodies.

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EIP-AGRI Focus Group
Sustainable industrial crops

MINI PAPER 4: Industrial crops for marginal and contaminated lands and for intermediate crops and intercropping strategies

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Authors

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1. Introduction

Over the last 20 years marginal and contaminated lands have received wide scientific and policy attention due to the increasing pressures on land as a result of population growth, growing food consumption and demand for biomass feedstock for bioenergy and biomaterials. Marginal land accounts for about 36 percent of global agricultural land (1.3 billion ha), and supports roughly one-third of the world's population.

In addition, it has been estimated that there are more than 10 million major contaminated sites worldwide, while in the European Economic Area (EEA) of 39 countries, there are up to 650,000 registered contaminated sites. Even though often perceived solely as a problem, contaminated areas could instead become a real asset that can actually create value.

The cultivation of industrial crops is generally promoted and supported for non-food purposes on marginal and contaminated lands. Most of these crops are used to produce a number of value added bio-products as well as bioenergy, thus contributing to the biobased economy. In recent years, a debate has emerged regarding food security and land use for bioenergy/industrial non-food crops. Cultivating industrial crops on marginal and contaminated land, unsuitable for food production, is consistently proposed as a viable alternative to minimize land-use competition for food production, and its adverse effects on food security, land based GHG emissions and biodiversity loss. Extensive literature already exists investigating the potential of energy crop cultivation in trace element-contaminated soils (Meers et al. 2010; Van Ginneken et al. 2007; Zhang et al. 2015). Nowadays, biomass production is focused on second-generation, low-input perennial energy crops, for example *Salix* spp., *Panicum virgatum*, *Spartina pectinata*, *Miscanthus* spp. (Dohleman et al. 2012; Guo et al. 2015; Clifton-Brown et al. 2017). Such plants have much lower input requirements and produce more energy along with reduced greenhouse gas emissions per hectare than first-generation annual food crop species (e.g. *Zea mays*) which have been used previously (Schrama et al. 2016). There are a number of commercially available energy crop species which have also been tested with success for their phytoremediation effects on arable land. However, further research is very much needed to demonstrate their robustness for large-scale heavy metal remediation applications.

Another important aspect addressed by this mini paper is the use of industrial crops as intermediate crops and in intercropping. Intermediate crops are crops that are usually an off-season crop planted after harvesting the cash crop while intercropping is a multiple cropping practice that involves the cultivation of two or more crops on the same field. Choosing intermediate crops or intercropping systems have to take in consideration not only the aim of it (e.g. provide weed control or nitrogen), but also the identification of the best time and place and simulation of the use of crops which can help to address current society challenges, e.g. soil and water conservation, carbon sequestration, mitigation of greenhouse gas emissions, sustainable intensification of cropping practice, and food security.

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2. Marginal & contaminated lands in Europe

2.1. Definition and current situation

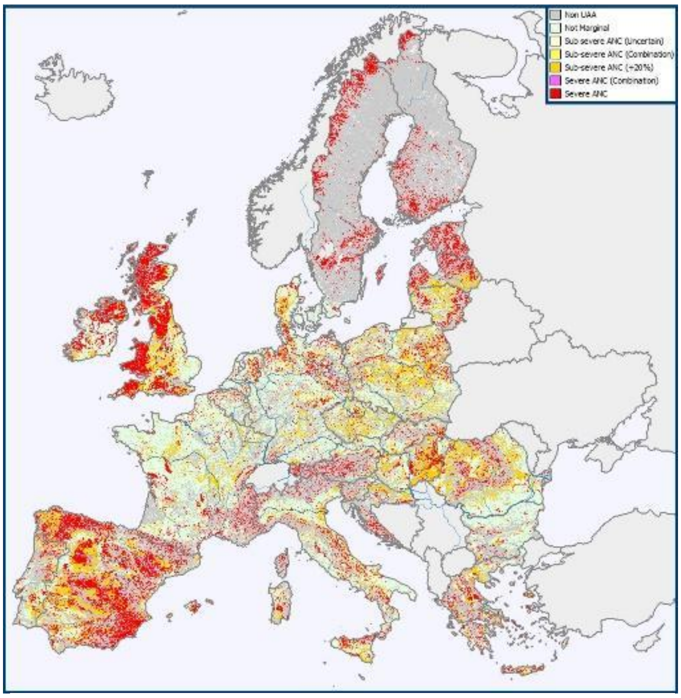

Figure 1. Marginal lands based on biophysical constraints in EU-28 (Elbersen et al., 2018b)

Marginal land is typically characterized by low productivity and reduced economic return resulting in severe agricultural limitation. Usually they need increased inputs to maintain their productivity however irreversible degradation is always a significant risk. The main constraints which marginal lands face are:

1) biophysical such as soil (unfavourable texture, stoniness, low fertility, poor drainage, excess soil moisture, shallowness, salinity, toxicity), steepness of terrain and/or unfavourable climatic conditions, and

2) socio-economic, such as absence of markets, difficult accessibility, restrictive land tenure, smallholdings, poor infrastructure, and/or unfavourable output/input ratios.

Krasuska et al. (2010) suggest a total area available for non-food crop production in the European Union of up to 13.2 Mha. According to this study most of this land is allocated in Eastern Europe. Figure 1 shows a map of the area of marginal land in EU-28 developed in the context of the MAGIC project (magic-h2020.eu) (Elbersen et al., 2018b).

Contaminated land is defined as land containing hazardous substances in or on it that are reasonably likely to have significant adverse effects on the environment (including human health). The most frequent contaminants of soil in Europe are metal(-loid)s, affecting 35% of European soils (European Commission, 2013; Van Liedekerke et al., 2014). These elements arise in the environment from various sources, such as industry, mining, smelting, agriculture, transport, wastes and fossil fuel combustion. Contaminated land is unsuitable for food production and therefore should represent an alternative option for biomaterials and bioenergy feedstock crops, as these crops would otherwise be in competition with food production. The exploitation of contaminated lands could open new economic opportunities and support the development of a rural economy. The Forum of European Geological Surveys (FOREGS), along with the Land Use/Land Cover Area Frame Survey (LUCAS) of the European Union (Tóth et al., 2016) acquires detailed information on the soil cover in Europe, including heavy metals and metalloids (from now on called metal(-loid)s) content. From this, a series of maps predicting total soil concentrations in As, Cd, Cr, Cu, Pb, Zn, Sb, Co and Ni in the EU was produced (Figure

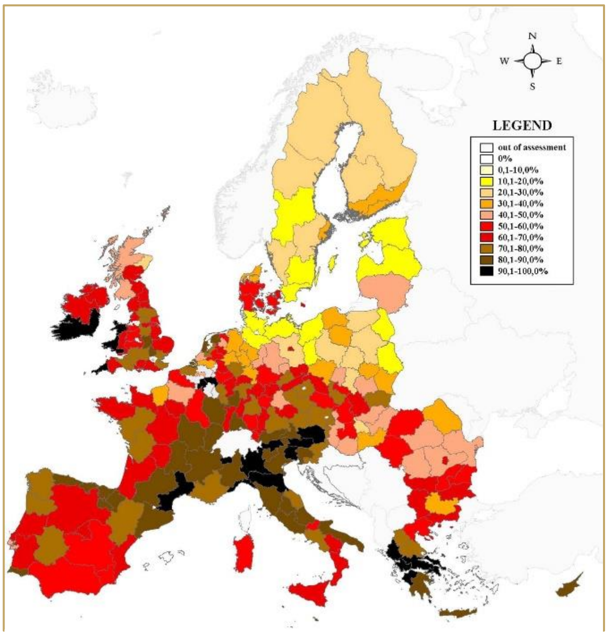

Figure 2. Soil samples (%) with concentrations above the threshold values (Tóth et al., 2016)

2). This map indicates whether one or more of these elements exceed the applied threshold concentrations in 28% of the total surface area of the EU.

2.2. Benefits from the exploitation of marginal and contaminated lands

Marginal and contaminated lands are extensive underutilized resources, which could and should be used in a sustainable way to grow plants for a large variety of profitable purposes. The most important benefits from exploiting these land areas by cultivating industrial crops include:

- supporting the restoration of marginal and contaminated lands
- conventional agricultural land will be freed for food and feed production
- reduction in the exposure to contaminants thus benefiting human health
- developing additional income for local farmers and population
- increasing the number of jobs and stimulating innovative entrepreneurship
- increasing the availability of domestic raw materials for use in new emerging markets
- increasing the vegetation cover thus decreasing erosion and desertification
- minimising the transportation of pollutants to other non-contaminated sites (via the air, surface runoff and/or by leaching to the underground aquifers)
- facilitating long-term carbon sequestration

2.3. Phytomanagement of contaminated lands

Phytoremediation is the non-invasive, cost-effective and publicly acceptable strategy of using green plants to remove contaminants from the environment or to render them harmless. This technology is used for the remediation of inorganic (metal, metalloids, etc) and/or organic (aromatic hydrocarbons, pesticides, etc) contaminants. However, due to limitations of space and time, this mini paper will only address inorganic contaminants.

The two main sub-technologies of phytoremediation are:

- **Phytoextraction**: where plants remove metals from the soil and concentrate them into their harvestable biomass.
- **Phytostabilization**: where plants reduce the mobility and bioavailability of contaminants in the environment either by immobilization or by prevention of migration.

A new and more recent aspect of phytoremediation is **phytomanagement** in which non-food high biomass yielding crops are used to reduce and control risks arising from soil pollution, while simultaneously assuring a profitable and sustainable use of contaminated sites by producing marketable biomass. Several recent studies focus on fast growing, high yielding and high value non-food crops, that could be used as a feedstock for bioenergy, as well as for a wide range of products with different industrial scale applications (e.g. construction biomaterials, bio-lubricants, bioplastics, pulp for paper, biopolymers, biochemicals, biofuels, biochar, etc). Prospectively, the exploitation of contaminated lands could open new economic opportunities for local farmers and rural communities by increasing the availability of domestic raw materials for use in new emerging markets. Such opportunities could stimulate innovative entrepreneurship and job creation and in the long term support a rural renaissance thriving within a biobased economy.

2.4. Management of waste water and polluting effluents by using plants

In certain regions of the EU, the potential for trees to perform a role in wastewater management with environmental protection has been implemented and is proving to be a successful and low carbon natural treatment solution. For example, Northern Ireland and the Republic of Ireland currently face many competing economic and environmental pressures, many of which will continue to be compounded by climate change. These include intensifying agriculture, increasing populations, aging wastewater treatment infrastructure and increasing pollution; all negatively affecting water quality. In these applications, wastewater from municipal treatment works, farmyards, agri-food processors and other origins is irrigated to willow plantations, in accordance with environmental and waste regulations, whereby the waste nutrient is managed by the soil/plant system. In this way, natural treatment systems can be utilised to manage societal wastes while simultaneously protecting the environment and contributing to a bio-resource supply chain.

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Poplars also grow well on contaminated lands helped by their longer rotations. Grasses grown on contaminated lands have to be constantly harvested and removed in order to decrease the level of soil contamination. Poplars, however, may be harvested once in 15-20 years with constant annual accumulation of contaminants in wood. This is similar for willows however, a more regular, and mechanised, harvest would be anticipated (2 to 5 years).

Figure 3. Leachate treatment system with poplars on former landfill (Canada)

Furthermore, several studies have reported landfill leachate to be successfully recycled and treated using Short Rotation Coppice (SRC) systems and bio-filter systems. In Sweden a number of such leachate treatment systems now operate. The Ireland and UK climate is arguably even more suitable for growing willow and the application of these systems would be an innovative approach for managing this polluting wastewater from historical, unregulated and operating landfill sites. The UK Environmental Agency (EA) has indeed approved the use of willow in managing leachate under certain licence conditions. Furthermore, their linkage to Integrated Constructed Wetlands (ICW) would also be a pioneering and novel approach to a very complex and costly set of environmental issues (Figure 3).

3. Industrial crops near to practice and suitable for marginal lands

3.1. Description and categorization of industrial crops

Industrial crops can provide abundant renewable biomass feedstock for the production of bioenergy and high value bio-based commodities (i.e. bio-plastics, bio-lubricants, bio-chemicals, pharmaceuticals, bio-composites, etc.). Many of these crops are multipurpose and provide an opportunity for a cascade bio refinery concept and to feed the bio based economy. However, their uptake by European agriculture is still very limited. However, Europe has a few small companies specialising in bio-based products and indeed several major chemical companies are developing bio-based applications. At this point, it is worthwhile mentioning that in 2010 the European chemical industry used about 8-10% renewable materials in the production of various chemical substances and polymers.

Industrial crops can be categorized into four main groups, namely: perennial herbaceous crops, annual herbaceous crops, oilseed crops and woody crops. The most important representatives of each category are presented in the Table included in the Annex.

3.2. Risks and benefits

In order to meet the EU renewable energy target, the demand for biomass is increasing sharply. The potential for land use conflict is also increasing as competition for food and feed comes sharply into focus (Dauber et al., 2012). Therefore, targeting the growth of dedicated industrial crops on marginal land is one clear way of overcoming these conflicts (Fernando et al., 2018a). However, studies on the cultivation of industrial crops in marginal soils indicate that its sustainability depends largely on the productivity. Loss in productivity will reduce the energy balance, the greenhouse savings and of course the economic return as outputs will be lower (Schmidt et al., 2015) while inputs are the same or even higher (e.g. need of higher amounts of fertilizer to help address the marginality of the soil) (Fernando et al., 2018a). Lower yields may also lead to aerial biomass with a higher content of ash, minerals (e.g. potassium) and nitrogen, which may hinder its industrial use (Fernando et al., 2015). However, depending on the type of marginality, biomass productivity may not be affected. An example of this would be when the soil type or physical condition (e.g. water availability) might affect traditional food or feed crop yields, however not necessarily a specific chosen industrial crop as a result of the different tolerance character. Moreover, the presence of a vegetative cover and the incorporation of crop residues into soils may restore soil properties (fertility, structure, organic matter), preventing soil erosion, and increasing biological and landscape diversity (the higher the complex structure and heterogeneity of a vegetation system the higher the cover value for wildlife and landscape values) (Fernando et al., 2010). As such, industrial crops can serve to restore ecosystem services and soil functionality helping to restore marginal lands. Thus, the cultivation of industrial crops in marginal soils may provide an efficient low-cost alternative to help recover marginal soils and help secure economically viable biomass production for industrial uses. In addition, accumulated organic carbon may represent an option for carbon credit programs.

4. Industrial crops near to practice and suitable for contaminated lands

4.1. Phytomanagement of soils contaminated with heavy metals and metalloids

Industrial crops suitable for phytomanagement are those possessing a series of characteristics, namely:

- tolerance to contaminants,
- ability to uptake the contaminants and/or stabilize them in soil fractions in relatively high levels,
- fast growth and high biomass yield,
- widespread highly branched root system,
- low input requirements and easy harvest ability,
- non consumable by humans and animals.

Several high biomass yielding non-food industrial crops have attracted much interest for their phytomanagement potential, such as miscanthus, industrial hemp, castor bean, cardoon, giant reed, kenaf, switchgrass, sorghum, poplar, willow, etc (Table 1). Although the metal bioconcentration capacity of these crops is much lower than the corresponding capacity of hyperaccumulator plants, the final metal uptake could be similar. These crops can provide feedstock for the production of bioenergy and for several industrial applications.

Table 1. Industrial crops near to practice and suitable for phytoremediation/phytomanagement

Name	Metal(loid)	References
Miscanthus	Pb, Cd, Zn As, Cr, Cu, Ni	Environ. Pollut. (2017) 225: 163-174 Environ. Sci. Pollut. Res. (2018) 25: 12096-12106 Environ. Pollut. (2019) 250: 300-311 Environ. Pollut. (2019) 252: 1377-1387 Bioenerg. Res. (2015) 8:1500-1511
Switchgrass	Pb, Cd, Zn, Cr	Environ. Pollut. (2019) 250: 300-311 Int. J. Phytoremediation (2019) 21: 1486-1496
Virginia mallow	Pb, Cd, Zn	Int. J. Phytoremediation (2018) 20: 1194-1204

Name	Metal(loid)	References
Cordgrass	Pb, Cd, Zn	Environ. Sci. Poll. Res. (2018) 25: 12096-12106 Environ. Pollut. (2019) 250: 300-311
Giant reed	Cd, Ni, Cr, As, Zn, Pb	Bioenerg. Res. (2015) 8:1500-1511 Environ. Int. (2005) 31: 243–249 Desalination (2007) 211: 304-313
Ind. Hemp	Cd, Cu, Pb, Zn, Cr, Ni, Hg	Ind. Crops Prod. (2004) 19: 197-205 Ind. Crops Prod. (2002)16: 33-42.
Flax	Cd, Ni, Pb, Sb	Ind. Crops Prod. (2004) 19: 197-205 Biotechnol. Adv. (2009) 27: 555 -561
Kenaf	Pb, Cd, Zn, Cr	J. Environ. Sci. (2008) 11: 1341-1347 Biodegradation (2013) 24: 563–567 Ecotoxicol. Environ. Saf. (2016) 133: 509-518
Sugar beet	Cd, Ni	Ind. Crops Prod. (2017) 107: 463-471
Castor	Cd, Pb, Zn, As, Cu	Chemosphere (2020) 252: 126471 J. Environ. Sci. (2008) 20: 1469 -1474 J. Haz. Mat. (2009) 168: 479 -483
Camelina	Cd, Pb, Zn	Biotechnol. Biofuels (2014) 7: 96 AgroLife Sci. J. (2014) 3
Cardoon	Cd, As	Ecotoxicol. Environ. Saf. (2011) 74: 195-202
Willow	Cd, Pb, Zn, Ni, Cu	Environ. Int. (2002) 29: 529-540 Bioenerg. Res. (2009) 2: 144-152 UNASYLVA –FAO (2005) 221
Poplar	Cd, Zn, Al	Int. J. Phytoremediation (2009)12: 105-120 Environ. Poll. (2004) 131: 485-494.

4.2. Phytotreatment of organic wastes, landfill leachates and management of high phosphorus soils

By its very nature and source, substances such as landfill leachate and sewage sludge contain substances which, if present in high concentrations, may result in land or water contamination. The EU Sludge (Use in Agriculture) Regulations (1989) as amended as the Sludge (Use in Agriculture) Regulations 1990, SI 1990/880, exists to protect the environment from potentially toxic heavy metal release when these materials are applied to land. There has been substantial study into the uptake of heavy metals by willow recently driven by the wish to develop sustainable strategies to recycle organic wastes to non-food crops to safely utilize the nutrient and then subsequently to understand the extent to which willows could remediate heavy metal contaminated land. These studies have often revealed that willows are highly tolerant of heavy metals and indeed they can uptake significantly more heavy metals than other woody species or agricultural crops. For example, willows will uptake more Cd in the stem biomass than is normally applied to the crop from sewage sludge. Willow is also particularly good at bio-accumulating Zn and can uptake 1000 to 1500 g/ha/y from normal agricultural land. In comparison, the offtake in wheat (grain and straw) of Zn is typically 200 g/ha/y and >1g/ha/y for Cd (Alloway et al. 1998, Chaudri et al. 1995). Cu and Ni uptake by willow are comparable or slightly greater than for wheat (Riddell-Black and Ferguson 2002).

Current literature is not overly resolute about the efficacy of willow systems to treat leachate, largely due to the presence of Nitrogen leaching (Aronsson et al. 2010), however this is not unanimous. There are positive effects and benefits and there are many currently running schemes (Swedish experience) which demonstrate good reasons to investigate the potentials in other EU soils, climate and varying leachates etc. The positive effect of the nutrient on plant growth (NH_4 utilised and not discharged to the environment) suggest strongly that N should be applied at crop uptake rate (Hasselgren, 2003), minimizing leaching. Such soil/plant systems have the ability to retain N, P and TOC as well as illustrate a strong resilience to leachate-induced stress (Dimitrou, Aronsson 2011). It is clear that leachate loading rates and timings are particularly important along with good plant growth with related evapotranspiration rate (McDonald et al. 2008). Short rotation coppices is clearly a potentially feasible method for leachate management.

Due to the land type and climate, parts of the EU such as Northern Ireland operate a dedicated grass based system which is difficult to deviate from. As such the agriculture industry is heavily represented by ruminants. This puts significant nutrient pressure on the receiving land bank as a result so there is now a growing urgency to put in place sustainable approaches to environmental protection and wastewater management to prevent damaging environmental water quality as a result of both point and diffuse sources of pollution. SRC willow is fast growing, takes up large volumes of water and can utilise the nutrients, in particular nitrogen and phosphorus. By targeting biofiltration blocks of willow in the landscape, these interventions could provide environmental protection from diffuse pollution by mitigating pollution from surface run-off into lakes, streams & ditches while at the same time producing a sustainable source of biomass. In N. Ireland, several agri-food processors and farmers have taken steps to proactively address these dual concerns (energy and pollution management) and facilitate the lowering of their production carbon footprint as well as their costs.

4.3. Risks and benefits

As direct or indirect land use changes, mainly caused by renewable energy initiatives, have frequently affected the food market in many areas, it is reasonable to encourage the cultivation of industrial crops on various types of marginal land, which includes contaminated land. Economically, the cultivation on contaminated land is in general more costly per tonne of produced biomass, in spite of the lower land rent price (Fernando et al., 2018b). Yet, the introduction of an industrial crop in a contaminated soil may also help to enhance the remediation of the soils, which is far less costly (economically and environmentally) than physical and chemical soil remediation techniques. The use of contaminated land to produce industrial crops can have a positive a socio-economic effect while increasing regional jobs. This stimulates the rural economy, by diversifying farming activities and by improving infrastructure for harvesting, storage, transport and logistics.

In addition, agricultural diversification to biomass crops can help address many environmental sustainability challenges. The exploitation of marginal and contaminated lands by industrial crops may support the reduction of desertification or indeed floods by increasing the vegetation cover and thereby reducing erosion and surface runoff. This will help decrease transportation of contaminants to other clean areas, reduce leaching to the groundwater, increase soil organic matter and carbon sequestration, promote soil biodiversity, protect soil structure and deliver several other important impacts that support the EU Sustainable Developments Goals.

A successful example is the short rotation coppice willow that has been established in 35,000 ha throughout the EU. This mainly exists in Sweden, Poland, Germany, Denmark, France and UK as well as lesser established areas in Italy, Ireland and Austria. The sole use for this biomass is as a biomass fuel for direct or co-combustion for heat or heat & power. The benefits of short rotation coppice crops include long-term soil stabilisation and soil health improvements. Root penetration into soil have potential to decrease soil bulk density and increase water infiltration and organic matter content. This rhizospheric activity, combined with leaf mulch, contributes to soil fertility through improved nutrient capture, retention and cycling. Moreover, it includes rural development through the creation of new markets and jobs, enhanced landscape diversity and wildlife habitat, and reduced erosion potential. Such benefits, while important features of willow biomass crops, are not readily captured by life cycle methodology.

Market-based forecasts show that the multiple benefits of renewable energy fuel sources will not be realized without proper regulatory or legislative incentive. While other less costly options exist to reduce air pollutants from existing fossil fuel power plants, biomass energy presents an opportunity to reduce air pollutants while also cutting greenhouse gas emissions and lowering non-renewable energy consumption.

Risks however are most often associated with the confidence of the market and supply chain. In the UK and Ireland, there have been a number of support schemes and plans to encourage the planting of willow and Miscanthus. These include Set-aside, Energy crops schemes, Bioenergy capital grants, Biomass processing challenge funds, Renewable obligations, Renewable heat incentives & support schemes for renewable heat. However to date, these have not increased the land area growing willow and Miscanthus by a significant amount; and certainly nowhere near the intended planting aspirations. In this parts of the EU, although experiencing success in reaching renewable electricity targets (predominantly through wind and solar), are coming up very short on achieving the renewable heat and transport fuel targets.

5. Industrial crops near to practice and suitable for intermediate crops and intercropping strategies

5.1. Description and applications

Intermediate crops are crops that are usually an off-season crop planted after harvesting the cash crop, replacing a fallow period. Usually those crops are planted to cover the soil rather than for the purpose of being harvested, contributing to system diversification and environmental performance. Above all, the value of year-round ground cover and root activity help to manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in an agroecosystem they also provide an additional income for farmers when grown for seed or feed, or as an energy crop. Moreover, diversification of crop rotations is considered an option to increase the resilience of crop production under climate change (Kollas et al., 2015).

An intermediate crop should satisfy the producer's primary reason(s) for intermediate cropping; be easy to establish and maintain with available equipment; be well-suited to the local climate and the farm environment; not compete with income-generating crops grown simultaneously or subsequently; and have the ability to withstand stresses likely to occur such as drought, frost, heat, etc. Some cool season options include some oil crops, such as rapeseed, and some warm season options include soybean and sorghum (Sharma et al., 2018).

Intercropping is a multiple cropping practice that involves the cultivation of two or more crops on the same field. This cropping practice targets the production of greater yields by matching efficiently a mixture of crops of different rooting ability, canopy structure, height, and nutrient requirement to the available growth resources (Lithourgidis et al., 2011). Different intercropping strategies which can be applied include:

- mixed or multiple cropping - the component crops are totally mixed in the available space (e.g. aromatic species and coffee);
- row intercropping – the different crops are arranged in alternate rows (e.g. maize and soybean);
- strip cropping - the different crops are arranged in alternate strips, where multiple rows, or a strip, of one crop, are alternated with multiple rows of another crop: a contour strip cropping follows a layout of a definite rotational sequence and the tillage is held closely to the exact contour of the field; or, a field strip cropping has strips with uniform width that follows across the general slope of the land (woody crops and sorghum);
- relay cropping - the planting of the second crop is made after the first one has completed its development (e.g. wheat and cotton).

Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a shorter crop that requires partial shade (Figure 4). Seed or biomass yield is the primary consideration to assess the potential of a specific intercropping system.

Figure 4. Cotton and wheat relay intercropping (Zhang, 2007)

5.2. Risks and benefits

The use of intermediate crops results in a number of economic and environmental benefits. Most crops benefit from the nutrients released by mineralising residues of the preceding crop, and intermediate crops are often used as crops that add nutrients to the soil (Kirkegaard et al., 2008), thus reducing the need for mineral fertiliser, in particular nitrogen (Askegaard and Eriksen, 2008).

Intermediate crops may enrich the soil with organic matter and help prevent rainfall from percolating through the soil and leaching nutrients out of the rooting zone of the main crop. Intermediate crops will also serve to maintain long-term soil fertility and habitat quality for soil organisms and prevent erosion, while increasing the potential water supply to the crop by increasing the soil water storage capacity (Boardman and Favis-Mortlock, 2014, Kollas et al., 2015). The selection of suitable intermediate crops minimise pests or diseases when they have the ability to break the life cycle of pathogens and can also be used to control weeds (Kollas et al., 2015).

However, some potential drawbacks should be considered before deciding to include an intermediate crop. In some cases, the intermediate crop can require additional labour and expense, delay crop planting, or serve as an alternative host for crop insects or diseases.

Intercropping may bring about numerous environmental advantages such as improving soil fertility using crops that promote biological nitrogen fixation (which allows lower inputs through reduced fertilizer), increasing soil conservation through greater ground cover than sole cropping, reducing hillside erosion and utilising the land area more efficiently. Furthermore, it may also provide better lodging resistance for crops susceptible to lodging than when they are grown in monoculture, as the companion crop is able to give structural support. Intercropping also contributes to increasing biological and landscape biodiversity by providing a habitat for a variety of insects and soil organisms that would not be present in a single-crop environment. Intercropping also promotes lower pesticide requirements, thus minimizing environmental impacts of agriculture. In the work of Samarappuli and Berti (2018), forage sorghum-maize intercropping proved to have a lower environmental impact compared with maize in all evaluated categories, this was largely because forage sorghum has several agronomic advantages over maize such as having a higher efficiency in utilising P and K, and requiring less water, and N fertilizer.

Intercropping provides two or more different crops for the farm family in one cropping season, providing assurance against crop failure or against unstable market prices for a given commodity, especially in areas subject to extreme weather conditions such as frost, drought and flood. Intercropping therefore offers greater financial stability than sole cropping making the agricultural system particularly suitable for labour-intensive small farms. It also results in a potential increase for total production and farm profitability than when the same crops are grown separately, once planting two crops in close proximity can especially be beneficial when the two plants interact in a way that increases one or both of the plant's fitness (and therefore yield).

However, intercropping has some challenges such as the selection of the appropriate crop species and the appropriate sowing densities. As well as this intercropping will require extra labour in preparing and planting the seed mixture and during crop management practices including harvest.

6. Successful case studies

6.1. PERENNIAL HERBACEOUS CROPS

Miscanthus for marginal land – Miscanthus biomass options for contaminated and marginal land: quality, quantity and soil interactions – Projects MISCOMAR and MISCOMAR+

MISCOMAR and MISCOMAR+ aim at developing new techniques for biomass production on marginal land that could be used in many countries across Europe, in particular where marginal land management is an issue. MISCOMAR and MISCOMAR+ are testing several novel Miscanthus seed-based hybrids on marginal and contaminated lands at three locations in Europe (Poland, Germany and United Kingdom). Baseline soil reports confirm marginality of the sites selected for the field experiments. The UK site is marginal due to nutrient depletion, the German site is characterized by high clay and stone content and the Polish site (Figure 5) located in Upper Silesia Industrial Region, is classified as marginal due to the concentration of lead, cadmium and zinc being over permissible limits for arable soil. Miscanthus can be harvested at different times depending on the final use of the biomass. In this case study it was harvested during October as a green harvest for an anaerobic digestion feedstock and also in March as a brown harvest as a feedstock for direct combustion. Yielding potential of new seed based hybrids in most cases was at the same range as for Miscanthus x giganteus, especially at brown harvest. Next generation hybrids seem to be very suitable for cultivation especially in German and Polish climatic and soil conditions indicating that there is a strong potential for these new hybrids to result in lower cost plantation establishment.

Figure 5. Seed based Miscanthus hybrids grown on metal contaminated arable land in Bytom, Poland (MISCOMAR+, Institute for Ecology of Industrial Areas)

Miscanthus for biomass is an alternative non-food land use option. Miscanthus crops generally improve the soil fertility through the increase of soil organic matter and activation of soil life; while the root and rhizome mass contribute to further soil carbon sequestration. The slightly increased heavy metal concentrations in the biomass cultivated at heavy metal contaminated arable land in Poland had no negative effects on the ash melting behaviour. For anaerobic digestion, a harvest before winter seems to be favourable, as slightly higher substrate specific methane yields can be achieved. Results show that increased heavy metal content in biomass does not negatively affect anaerobic digestion. What was a bit surprising however was that Miscanthus, due to very low concentration of heavy metal in the biomass, is not suitable for phytoextraction, as was expected. On the other hand, it was confirmed that Miscanthus cultivation could be a safe and profitable option for marginal and contaminated lands. In MISCOMAR+ (2020-2023, under FACCE SURPLUS) new approaches will be tested on the same three demonstration sites. These will include agronomic treatments for better Miscanthus survival, monitoring of long term yield persistence and monitoring of biomass quality and impacts on soil health indicators. Furthermore, this will also be instrumental in developing and optimising sustainable, economic and environmental-friendly valorisation options for biomass from marginal and contaminated lands and will allow for analyses of socio-economic and environmental impacts on growing the crop on such degraded soils.

6.2. OILSEED CROPS

Oil crops, rich in fatty acids that can serve as sources for medium-chain polymer building blocks, can be used for the production of innumerous products, e.g. surfactants, detergents, lubricants, plasticizers, replacing fossil-based feedstocks. But oil crop production for bioenergy, biofuels, bioproducts or biomaterials competes directly with oil crops for food through land use, a conflict that can be avoided if these oils crops are cultivated in contaminated soils. In the framework of the MAGIC project (https://magic-h2020.eu), trials are being conducted in different climatic zones of Europe focusing on the effects of soils contaminated with different heavy metals (Pb, Zn, Cd, Ni). Specifically, these trials are investigating the effects on growth, yields and the characterization the biomass from different oil crops (*Camelina sativa*, *Brassica carinata* and *Thlaspi arvense*). Preliminary results indicate that *B. carinata* and *C. sativa* growth were not significantly affected by heavy metal contamination at the levels tested (Zn: 450/900 mg/kg; Pb: 450/900 mg/kg; Cd: 4/8 mg/kg and Ni: 110/220 mg/kg). Conversely, however, all the heavy metals affected the growth of *Thlaspi arvense*. It was noted however that heavy metal contamination, specifically Ni and Cd contamination, significantly reduced the number of siliquae, which is likely to reduce the economic viability of oil crop cultivation in heavy metals contaminated soils. However, preliminary data indicates that the increased accumulation of metals in the siliquae fraction of all oil crops tested was minor in comparison to those from uncontaminated soils (Costa et al. 2019, 2020). This result agrees with what was observed with seeds of spill-affected sunflower plants cropped from the Agrio and Guadiamar river valleys in southern Spain after the collapse of a pyrite-mining tailing dam in 1998. This incident contaminated approximately 2000 ha of cropland. Seeds of the spill-affected sunflower plants did accumulate more As, Cd, Cu and Zn than controls however, the values were below toxic levels (Murillo et al., 1999). Future research will help clarify if the oil content and the composition of the oil changes with the contamination. Some studies pointed out that under severe heavy metal stress, sunflower proteasome activity is reduced and this results in accumulation of oxidized proteins (Pena et al., 2008). In addition, some studies also denote that the metals remain in the seed meal and not in the oil, and the organic acidic salt, potassium tartrate which is often used as a food additive, can be used to extract heavy metals to a level that is lower than permissible amounts established by legislation (Yang et al., 2017).

6.3. WOODY SPECIES

Willow for wastewater management in Northern Ireland

In 2007, the Department of Agriculture in Northern Ireland funded some research & development examining whether willow plantations could be used to bio/phyto-filter wastewaters from farm yards. The results have shown no indication of negative environmental impacts, a high degree of remediation of water and a substantial uptake in nutrients (Forbes et al 2017). The knowledge, experience and interest which this project succeeded in developing gave rise to the EU-Interreg lV ANSWER project which succeeded in the planting of over 100 acres of SRC willows for the dual purposes of waste water management and the simultaneous production of bio-resources for bioenergy. Although at the time bioenergy was, and still is, the prime use of this bio-resource, it is clear that there are other higher value uses which could emerge. Waste water treatment works (WWTW) with marginally compliant discharges, as a result of infrastructure age and population increase, were adapted to irrigate the treated effluent to the willow plantations. One such site in Bridgend, County Donegal, has been running since 2014. This WWTW serves a population of approx. 650 people. Historically the treated wastewater was discharged into the adjoining river however it is now largely irrigated onto 14ha of willows. The results from the 2014 summer period revealed an 85% reduction in discharge from the plant into the river (rising to 93% in 2018) during the growing season when the river is most often experiencing low flow and is most chemically and ecologically vulnerable. The willow crop has been harvested twice since establishment.

Over the last five years, over 50% of the treated wastewater has been recycled to the willows, on a yearly basis, with this level rising to over 80% when the summer months are viewed specifically. Generally, during the summer months rainfall is less, receiving water flow is lower, light and heat availability are higher and as a result the receiving water body is most vulnerable to pollution, eutrophication and ecological deterioration. Maximum benefit can be derived by discharging to the willow crop during this period as conversely, this is when the willow will have a high evapotranspiration rate, protect soil & ground water and also have high nutrient assimilation potential for N & P encouraging maximum yields. The use of willows for waste management and phyto / bioremediation, as well as the greening and cleaning up of contaminated sites, can aid in the uptake of plant macronutrients but also the removal and bioaccumulation of heavy metals such as cadmium, copper, nickel & zinc (Table 1) which will be retained in the combustion ash if used for bioenergy.

Willow for water quality protection in Northern Ireland.

Northern Ireland has a large and successful livestock sector however it is well recognised that the intensity of this livestock agriculture (Dairy, Beef, Pig, Poultry) is putting excessive pressure on the 'receiving' land base for nutrient recycling (Figure 6). Due to the land type and climate in Northern Ireland, it is difficult to deviate from a grass based system and as such NI's agriculture industry is heavily represented by ruminants. The recent EU WaterPro project and more recently the EU CatchmentCARE project are investigating the practicality of using SRC willow biofiltration blocks and buffer strips to try to intercept some of the overland runoff of nutrients coming from the pastureland and in doing so, protect the receiving water bodies. The figure below represents a proof of concept willow biofiltration zone, targeted as a result of LiDAR and digital terrain mapping, planted to intercept overland nutrient runoff. The biomass is harvested regularly and is used to fuel the biomass heat systems distributing water through a district heating system.

Figure 6. Willow Biofiltration zones planted at the Agri-Food and Biosciences Institute, Hillsborough, Northern Ireland, UK

Willow for Waste management in Lithuania

In Lithuania, the EU LIFE project "Nutrient recycling circular economy model for large cities – water treatment sludge and ashes to biomass to bio-energy" (NutriBiomass4LIFE) is being implemented to demonstrate a full-scale self-sustainable closed-loop circular economy model for nutrient-rich waste recycling for Vilnius, with 0,5 million population. This involves reusing all the municipal sewage sludge digestate (derived after biogas production and pelletising) and biomass ash on biomass plantations close to the city. The project seeks to develop new business models to make it economically viable (via increased yields while using nutrient rich wastes and additional revenues from phyto-management services) to grow woody biomass on marginal lands. 900 ha of existing poplar and hybrid aspen plantations were mobilized and an additional 900 ha of poplar plantations are being established on marginal lands with the purpose of serving the phytoremediation needs of Vilnius city. This project is described in detail in Mini Paper 2 - "Selected Value Chains on Industrial Crops".

Similarly, the Interreg IVA "Agricultural Need for Sustainable Willow Effluent Recycling" (ANSWER) succeeded in the establishment of 40 ha of willow plantation in Ireland for the management of treated waste water from a number of conurbations. To date, these sites are operating sustainably with the willow biomass harvested for use in heat and power generation locally. These concepts are being progressed further within the Interreg VA CatchmentCARE project which aims at improving freshwater quality within cross border river catchments.

6.4. SUCCESSFUL CASE STUDY OF INTERMEDIATE CROPS

Camelina as intermediate crop

Camelina is a resilient oilseed crop, characterized by high environmental plasticity and low input requirement, thus making it suitable for different European pedoclimatic conditions. One of camelina's main differentiating characteristics as an oilseed crop is its precocity, as there are European varieties that have been developed for cultivation in 80 to 90 days from sowing to harvest.

Additionally, camelina provides different key characteristics that make it an ideal cover crop solution:

- easy implementation, with the capacity for germinating rapidly when sown shallow (< 1cm);
- quick soil cover with allelopathic effect, which allows for good weed competition;
- good water efficiency, especially for low rainfall conditions (< 250 mm);
- excellent cover crop choice to avoid nitrogen leaching;
- better tolerance to pests than other crucifers;
- melliferous species, providing a source of nectar and pollen to bees at a critical moment of the year.

Camelina Company España, in collaboration with Saipol (Groupe Avril), have been carrying out camelina intermediate crop (catch crop) plantations in different regions in France since 2018 (Figure 7). Camelina is introduced as a summer catch crop -not displacing any main crop- following a proteaginous crop (peas) or a winter cereal (barley, wheat, rye), and harvested in October before the following winter crop sowing. Camelina replaces a fallow period providing the agronomic and environmental benefits of a cover crop during the summer, while also granting farmers an additional income. Camelina harvest potential under these sustainable catch crop conditions reaches ~2,000 kg/ha, depending on climate conditions, as well as very high Green House Gas emission savings (exceeding 80%). As land availability exceeds 10 million hectares in Europe, camelina catch crop is a sustainable feedstock with large volume potential for advanced biofuel production.

Figure 7. Camelina cultivated as a catch crop in France

6.5. SUCCESSFUL CASE STUDIES ON INTERCROPPING

Camelina in intercropping

Camelina intercropping is mostly performed with legumes, as the symbiotic N-fixation and residue incorporation also contributes to further ameliorating the soil fertility. While in conventional farming systems camelina intercropping is not usually adopted, in organic farming it is more commonly used, especially in France and Germany, to successfully manage some of the main issues related to organic systems such as weeds and diseases.

Camelina is usually employed in intercropping with lentils or peas, as it acts as a tutor during legume development, allowing for a win-win solution that provides the following benefits:

- early soil coverage, especially in winter, enhancing the efficient use of natural resources (e.g. water), preventing N-leaching and soil erosion;
- reduction of herbicide use in the whole crop rotations (not only in camelina and legumes) due to the camelina quick soil cover and allelopathic effect together with the competitive advantage over weeds.
- reduction in the need for fungicides as the camelina tutor effect reduces the legume contact with soil humidity;
- reduction in legume harvest losses, also due to camelina tutor effect;
- increased economic performance of European farming systems due to 'eco-friendly agronomic management' (savings in irrigation, nutritional needs, pest/weed control etc.),
- new market opportunities, especially for the animal feed industry, as camelina seed contain high protein content (above 25%, on dry matter basis), with high quality amino acid profile.

GEVES, in collaboration with Camelina Company España, has carried out camelina/lentil intercropping plantations in the western Poitou-Charentes area in France (Figure 8). The intercropped plantation resulted in a harvest of lentils of 2.200 kg/ha, while pure lentils cultivation resulted only in 2.100 kg/ha. The increased lentil harvest was due to lower harvest losses. It also had better quality with fewer broken lentils and with fewer disease problems.

Figure 8. Camelina/lentil intercropping carried out in France.

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8. Annex

Industrial crops near to practice and suitable to be cultivated: (i) on marginal and contaminated lands, (ii) as intermediated crops, and (iii) in intercropping.

Name	Cultivation in Europe			Uses	Cultivated in land		Cultivated as	Cultivated in
	North	Central	South		Marginal	Contaminated	Intermediated crop	Intercropping
PERENNIAL HERBACEOUS CROPS								
Miscanthus *Miscanthus x giganteus* Family: Poaceae	+	+	+	Solid biofuels, advanced biofuels, other industrial applications	+	+		+
Switchgrass *Panicum virgatum* L. Family: Poaceae	+	+	+	Solid biofuels, advanced biofuels, other industrial applications.	+	+		
Cordgrass *Spartina pectinata* Family: Poaceae	+	+	+	Combustion and co-combustion, Gasification		+		
Virginia mallow *Sida hermaphrodita* Family: Malvaceae	+	+	+	Combustion and co-combustion, Gasification, Anaerobic digestion		+		
Giant reed *Arundo donax* L. Family: Poaceae			+	Solid biofuels, advanced biofuels, paper pulp, building materials, etc.	+	+		+
Cardoon *Cynara cardunculus* L. Family: Asteraceae			+	Energy from biomass combustion, biodiesel from seed oil, fiber supply for pulp and paper, pharmacological active compounds, etc.	+	+		+

Stinging nettle *Urtica dioica* L. Family: Urticaceae	+	+	+	Bioenergy, textile/fibres, medicines, cosmetics, animal bedding, etc	+			
ANNUAL HERBACEOUS CROPS								
Sorghum *Sorghum bicolor* L. Family: Poaceae		+	+	Biofuel, food, animal feed, fibre. Sorghum is a great fibre source.	+	+	+	+
Industrial hemp *Cannabis sativa* L. Family: Cannabinaceae	+	+	+	Valuable essential oils, fibre, textiles, bio-composites, bio-fuel, cosmetics, paper	+	+		
Sunn hemp *Crotalaria juncea* L. Family: Fabaceae			+	Fiber, green manure, fodder	+		+	
Kenaf *Hibiscus cannabinus* L. Family: Malvaceae			+	Textiles, pulp for paper, building and insulation materials, bioplastics, organic absorbents, bioenergy	+	+	+	
Flax *Linum usitatissimum* L. Family: Linaceae	+	+	+	Several industrial applications from its oilseeds and its fibre stems. Important nutraceutical and pharmaceutical uses.	+	+	+	
OILSEED CROPS								
Castor bean *Ricinus communis* L. Family: Euphorbiaceae			+	Source of ricin oleic acid with several chemical and medicinal applications. Its oil has an international market with more than 700 uses.	+	+		
Crambe *Crambe abyssinica* L. Family: Brassicaceae	+	+	+	Its oil has high erucic acid and has several industrial applications	+	+		+

Camelina *Camelina sativa* L. Family: Brassicaceae	+	+	+	Its oil has a major application in sustainable low carbon biofuels as well as in other applications in the chemical industry for the production of a large variety of high-added value bio-products. The cake of the seeds has high protein content and is a valuable source for animal feeding.	+	+	+	+
Safflower *Carthamus dictorius* L. Family: Asteraceae		+	+	Food, dyes, medicines, biopolymers, surfactants, etc	+	+		+
Cardoon *Cynara cardunculus* L. Family: Asteraceae	as before				+	+	+	+
WOODY SPECIES								
Willow *Salix* spp. Family: Salicaceae		+	+	Solid biofuels, advanced biofuels, biobased products (construction materials, packaging materials, etc.) paper & pulp.	+	+		+
Poplar *Populus* spp. Family: Salicaceae	+	+	+	Combustion, gasification, pyrolysis. Use in traditional wood processing, furniture and construction industries. Novel uses for liquid biofuels (bioethanol), biochemicals and bioplastics – similar processing pathways developed for lignocellulosic crops – as poplars can be big resource for this novel industry.	+	+		+
Black locust *Robinia pseudoacacia* L. Fabaceae		+	+	Solid biofuels, advanced biofuels, biobased products (furniture, construction materials, packaging materials, etc.) paper & pulp.	+			
Siberian elm *Ulmus pumila* L. Ulmaceae	+	+	+	Solid biofuels, advanced biofuels, biobased products paper & pulp.	+	+		+

EIP-AGRI Focus Group
Sustainable industrial crops

MINI PAPER 5: Review of Industrial crops as part of advisory, research and educational programmes in Europe.

JANUARY 2021

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1. Introduction

International deadlines for meeting renewable targets for greenhouse gas emission reductions and EU Policies such as the Farm to Fork Strategy (May, 2020) are a significant driver that provides an incentive for developing agriculture-based industrial cropping solutions. Increasing the uptake of industrial crops, at a time when there are limited or no new resources to do so, will require high confidence levels among farmers, processers and advisors relating to the agronomy and markets of such crops. A fluid exchange of information between all stakeholders is an important component of a successful bioeconomy. A great deal of information was gathered by Focus Group 40: Sustainable industrial crops. It is important that this information, industry experience and research findings are disseminated effectively throughout the EU.

A broad overview of the general knowledge needs and potential methods of information transfer is outlined throughout the paper. The recommendations are made within a context of the diverse European conditions observed and the existing resources that are available.

2. Current Status

The agronomy of industrial crops is relatively new in comparison to traditional agriculture. Growers of industrial crops need clear information to make the transition, particularly how to diversify sustainably ensuring displacement of food crops does not occur. An immense repository of information is available for a number of crops but there are still some gaps in knowledge and its delivery.

An overview of the knowledge requirements (non-exhaustive) and some of the available resources are outlined below:

Pre planting:

- The **identification** of a crop that has a market and that can grow in the farmer's soil is important at this stage. Identification of suitable soil for a particular crop is important including identification of fertiliser requirements, soil moisture profiles etc. Advice and examples are a good tool at this stage for both farmers and advisors. Tools like the MAGIC database of suitable crops on marginal lands may be a very useful tool specifically[1].
- Knowledge around **sourcing of planting material** is very important. Advisors and researchers can help farmers at this stage. A database of high yielding, disease resistant planting material is an excellent resource. Extensive research has been carried out on some industrial crops like willow. There is a very large repository of information on the numerous varieties of willow and their growing characteristics[2].
- Guidelines on **ground preparation**, planting schedules and **planning** are important tools. Again, some crops have excellent guidelines available[3,4] on the planning of these crops. An important aspect of this knowledge transfer is offering opportunities and information on requirements for growing crops on marginal/contaminated land, combining industrial crops with food crops or utilising agroforestry techniques etc.

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[1] http://magic-h2020.eu/reports-deliverables/
[2] https://www.teagasc.ie/media/website/publications/2012/Willow_Identification_Guide_2012.pdf
[3] https://www.teagasc.ie/media/website/publications/2011/Short_Rotation_Coppice_Best_Practice_Guidelines.pdf
[4] https://www.teagasc.ie/media/website/publications/2011/Miscanthus_Best_Practice_Guidelines.pdf

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Planting and growing of crops:

- **Machinery requirements** are an important consideration for farmers planting new crops. Good information on the required machinery and **availability** of such machinery is very important for farmers. Also, information on possibilities of **adapting machinery** which farmers already possess is critical to the viability of the sector.
- Advice on **weed/pest control** while growing crops is important. Numerous research projects are investigating the potential of integrated pest control (IPM) in forestry and crops. This will be an important aspect of sustainable industrial crops along with information on organic growth of crops.

Harvesting Crops:

- The physiology of some industrial crops can be very different to traditional crops. Information on **adaptions to machinery** to ensure efficient harvesting of diverse crops is critical to ensure costly mistakes do not occur. Advisors, industry partners and researchers have an extensive library of knowledge in these areas that can be shared with new entrants.
- Optimal **harvesting times** can vary greatly for industrial crops. The concentration of important components in crops can vary throughout the year and harvesting at the certain times ensure higher yields (e.g. salicylic acid in willow crops peaks at various times of the year).

Selling/Processing Crops:

- Information on **markets, market requirements and how to access them** is of vital importance for all stakeholders.
- Access to information on new **processing techniques and machinery** is important to ensure efficiency in the industrial crop sector.
- **Legislative, legal and business information** is important to farmers if they wish to become processers and have a product ready for sale. Farmers are excellent entrepreneurs and have immense potential to become processers to enhance profit margins. An important step to help farmers is the provision of easy access to clear guidelines and advice on access to markets, business set up requirements, legislative and legal requirements etc.

Marketing/Distribution of Crops:

- Information on setting up **cooperatives** to allow economies of scale and a **unified approach** to marketing, logistics and sales is important and can be helped with information flow between different organisations and countries.
- Biomass trade centres have been very successful in Europe for forestry and bioenergy crops and sharing information[5,6]. They have been used not only as centralised markets for sales but also as **demonstration pilots for innovations** in technology.
- Information on quality requirements and **certification** regarding sustainability, traceability, standardisation etc.

The transfer of information between farmers/processers, advisors and researchers has potential to be optimised throughout Europe. Farmer advisory services are very efficient in transferring knowledge on traditional crops however less so when it comes to new innovations or knowledge that is under development or production chains which may be adapting to specific operative conditions.

The transfer of information from research to advisory and farmers/processers and vice a versa can be challenging. Scientific communication is a complex process for which scientific competence and

[5] http://www.agriforvalor.eu/innovations/Biomass-Trade-Centres-for-Value-added-Applications-5
[6] http://www.biomasstradecentre2.eu/biomass-trade-and-logistics-centers/

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communicative efficacy are required. Scientists tend to have minimum requirements they must achieve in communicating their finding to the research community that may not be appropriate for advisers or farmers.

3. Innovation Needs and Potential Operational Groups

The following general observations and recommendations are a prelude to the needs for Operational Groups and Innovation Needs:

- It is difficult to convince farmers about novel crops Farmers need to understand how to grow industrial crops and have access to best practice guidelines. When the crops become more mainstream and traditional, there is a lot more agronomy understood about the crop and willingness to consider them increases.
- The industry needs to be sure that they are receiving a good quality product. Industry needs farmers to produce to a recognised quality standard otherwise the supply chain will break down.
- Advisory services are reluctant to deliver messages on novel crops where they have no experience.
- The innovative potential of industrial crops needs to be developed with European agricultural advisory services.
- Very often advisors are referring farmers to associations or businesses associated with industrial crops like energy crops regarding varieties, harvesting etc. They are generally not referred to the national Agricultural Knowledge and Innovation System (AKIS) as they do not have this information. Growers of industrial crops could initially be directed to the AKIS within a country and then to grower organisations and associations thus enhancing the networking framework.
- Mechanisms to train advisors are needed. Advisory services need to understand both the agronomy of producing crops together with understanding the markets associated with a crop. Advisors do not want farmers to invest money in crops which do not give a return.
- If an advisor believes and has confidence in growing a crop this will inspire confidence in a farmer to engage with a particular crop. Advisory services need to be comfortable about dealing with novel crops.
- Research administrations across Europe should embrace the opportunity to direct more of their research resources towards helping achieve national goals within the EU framework while also ensuring information can be adaptable (where possible) to other areas in Europe in a mutually beneficial way.
- Sustainable integration of industrial crops into the current agriculture infrastructure can be successfully achieved by introduction of innovative approaches such as agroforestry, intercropping, novel rotations, use of marginal land, etc. This knowledge about combining intensive systems need additional advisory support.
- There are examples of tools for demonstration. Blade, Farm Demo, I2 Connect and Fairshare are examples of ways of disseminating information from advisers to growers.

4. Potential Operational Groups

EIP AGRI Operational Groups are an excellent way to bring together farmers, researchers, advisors, environmental groups, agri-business and NGOs to identify innovative ways to ensure knowledge is transferred efficiently throughout all stakeholders. Some suggested Operational Groups are proposed below:

- Standardisation by compiling the current repository of best practice guidelines for industrial crops, updating these guidelines and making them universally understandable, identifying missing crops that do not have guidelines and designing new guidelines, surveying farmers and advisors on what they would like to see in guideline documents and how they would like to receive them (online, physical copies, webinars etc.).
- Establishing a “Bio based Leadership Team” within Research and Advisory Services can be a strategic approach for developing and disseminating knowledge on bio-based industrial production. The Leadership Team could be responsible for:

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  - Identifying specific near term, high priority projects that would support the expansion of agricultural bio based renewable energy and other bio-based materials production, while not replacing food production;
  - Creating an inventory of internal and external personnel and facilities that could be utilised to plan and execute projects, including farmers and other actors of the value chains and
  - Developing an overall implementation strategy that expands the involvement of Advisory services in the formation of needed strategic partnerships to accomplish project and agency wide goals.
- Development of centres for industrial crop supply chains similar to the biomass trade centre's previously set up. These centres can take inspiration from successful traditional agriculture cooperatives and utilise efficiencies of scale. The cooperatives can be centres of knowledge transfer also; a one stop shop for guidelines and technical information on industrial crops.
- Create a group of experts similar to the Focus Group with an ongoing objective being to disseminate research in the area and achieve a technical panel status.
- The Agricultural Knowledge and Innovation System (AKIS) is a very important tool to suggest best practices to farmers. They are specific for the area where they are located and are very familiar with the local conditions. The local advisory service can give important technical support to farmers. However, the AKIS technicians are skilled mainly on the traditional crops within the area and normally they would not have a sufficient depth of knowledge on novel industrial crops that are under development within different research projects. They would also not normally be aware of the great potentials of emerging markets within the agro industry, the entities which are investing in the bioeconomy and the different partners fulfilling certain roles in the many and varied research projects. Recruitment of a group of AKIS, specifically for industrial crops that can advise stakeholders in the area would be valuable.
- Development of training material that is adaptable throughout Europe. The core modules can be universally applicable for each industrial crop like decision matrix, logistics development, identifying suitable land, how to prevent conflicts with food production, supply chain analysis etc. with specific crops that are suitable in each area being developed as examples. A universally recognised qualification in Industrial/Innovative Crops will help develop the confidence and skills throughout Europe to advance the area.
- Survey of the current pioneers in the area. Discover what specific challenges customers and stakeholders face that keep them from growing their bio-based enterprise. It does not matter whether the research or advisory service can solve all the industry challenges. This exercise will provide a supply chain context for needed research, business development, and policy solutions. Map all challenges along complete technology pathway supply chains, from feedstock production in the field to bio based / renewable energy production and end-use, and prioritise those aspects that problem-solving research can address. Build implementation into the strategy that clearly defines not only what work organisations will do (research and extension activities), but how accomplishments will positively benefit sustainable renewable energy and biobased production productivity, profitability and good stewardship of natural and human resources.

It is also important to consider how science could be used to support the development of Government policy. As partners are incorporated into strategic plans, it is important to establish lead responsibilities with defined roles aligned with each supply chain segment. Guiding principles regarding intellectual property protection, ownership, dissemination and recognition of accomplishments need to be established.

Dissemination and scientific communication

One of the researchers' tasks is to select the most appropriate means, strategies and places to direct the flow of information in the most appropriate and functional way. The target audience is a key consideration for researchers. In essence, it is possible to distinguish two macro-types of knowledge dissemination.

(1) There is an internal disclosure to the scientific community carried out preferentially through publication in specialised journals characterised by specific impact factors (IF), an index used to evaluate the quality of individual scientific publications. This can also be carried out through "uncensored research products"

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which are not catalogued in the database of the Institute for Scientific Information (ISI) but sometimes are of high scientific and cultural value. This type of disclosure is carried out following well-defined, rather rigid standards and systems and using highly specialised language.

(2) There is also a very important branch of information dissemination which must be directed to a wider and more varied audience which is often directly interested in the applicability of what is being disclosed and therefore has a "social impact factor" that is difficult to evaluate. In these circumstances it is likely that there is no use of "indexed research products" and therefore the rules followed and the context in which we operate must be completely different.

Diverse solutions must be implemented such as scientific articles in specialised journals, technical and popular publishing works, conferences, meetings with supply chain or agricultural organisations, seminars, training courses for sector technicians and indeed popular media.

Recommendations to researchers

Research organisations will need to develop streamlined research and development strategies that help move new discoveries or improved technologies and processes rapidly through the demonstration phase to full scale commercial use. Innovative public-private partnerships should be used to accelerate adoption of research and technology for the production of bio-based products. When choosing projects, clear pathways to commercialisation should always be identified. Initially focus on goals that can be achieved in five years or less will maximise initial impact and recognition. All technology development should be done with commercial outlets in mind, and with business partners who have a vested interest in and will adopt the technology.

Build purposeful partnerships with organisations that specialise in technology commercialisation and business development. Consider commercialisation efforts as an outgrowth of traditional agricultural extension and outreach, particularly to non- traditional kinds of customers and stakeholders with whom agricultural research organisations may not have previously worked with. Such an approach would provide additional value and recognition to research and advisory bodies and their commitment to agricultural-based biomaterials and renewable energy.

5. Case Studies

Greece - Case Study: Integrated Crop Management System in Cotton (OEKO-TEX)

This case study provides a good example of cooperation between public research bodies (universities, research institutes, ministry) and private companies (farmers, industry, agronomist, advisors) to promote the use of innovative technologies supported by the advisory services in the industrial crop sector.

Cotton is the most cultivated industrial crop in Greece with historic value as it has been established in Greek agriculture since 1870. About 400.000 ha are cultivated annually with cotton and over 1.5 million tons of cotton is produced. As an industrial crop all the production is transferred to ginning factories for further procedure.

Although there is great experience concerning cultivation techniques and inputs, a growing demand for innovative technologies and environmentally friendly techniques are needed by all elements of the supply chain that are involved in cotton production (farmers, industry, agronomists).

Concern regarding the environment and the quality of products especially,, have forced the introduction of an innovative Integrated Crop Management System for cotton cultivation. The significance of environment includes not only nature and the producer but the environment in which the action is taken as well.

funded by European Commission

For the development of the Integrated Crop Management System all involved parties have developed a cooperation. The universities, together with the Institute of Plant Breeding and Genetic Resources, have worked on the protocol and the Hellenic Agricultural Organization (HAO) DIMITER has published the formal Protocol for Integrated Crop Management in Cotton (AGRO 2 Cotton). The industry and the farmers are both part of the protocol as there are specific articles that concern the cultivation (farmers) and the post-harvesting procedure (ginning factories). The implementation of the protocol, that includes elaboration of required studies, training of farmers and industry workers and collaboration with public bodies and private cotton input trade companies, has been provided by certified agricultural advisors.

Integrated Crop Management System in Cotton aims at the reduction of surges, the import of innovative technology to the culture and finally, as far as it concerns the agricultural exploitation, it aims at the achievement of better possible economic results with the minimal environment perturbation.

The benefits from the application of an Integrated Crop Management System are:

- The assurance of both the culture output and the producer's income.
- The reduction of environmental repercussions as a result of agricultural activities.
- The response to the requirement of society and the market for the protection of the environment and eradication of synthetic chemical agricultural products.

Finally, the Integrated Crop Management System in Cotton (AGRO) has been adopted by a large number of cotton farmers and ginning industries in Greece and today about 150.000 ha of cotton are cultivated according to this protocol.

Furthermore, the ginning industry, by the adoption of the Integrated Crop Management System in Cotton, has met the requirements for the production of cotton wool according to the international STANDARD 100 by OEKO-TEX® which has provided added value to all chain of production.

Italy - The Italian experience in the dissemination of scientific innovations for the bioeconomy

The SUSCACE Project (Scientific Support for Agricultural Conversion towards Industrial Crops) was developed in Italy to respond to the concrete and urgent demand of research supporting the reconversion from sugar beet production towards energy crops. The project aims to:

1) Provide technical and scientific support to stakeholders, finding solutions to the problems they have identified.

2) Make technological innovations, strategic for the outcome of the supply chains, available to the farmers

3) Share the most recent acquisitions of scientific research with the stakeholders of the bio economy sector in order to help them in the choices of energy crops species, varieties and cultivation techniques in the different specific environment.

4) Disseminate the technologies developed by training the farmers to utilise new technologies.

The request of available technological innovations were related to the production of both herbaceous and arboreal industrial crops and the realisation of prototypes for harvesting, without which it would not be possible to reach the production of biomass to feed the processing plants at a reasonable cost. The project took into consideration agronomic, technological and mechanical aspects of fast-growing tree species (poplar, robinia, eucalyptus) and herbaceous oil species (rapeseed, sunflower, Brassica carinata, soya) and ligno-cellulosic herbaceous plants (common reed, sorghum fiber, hemp).

Researchers participating in the project had to develop a communication strategy to ensure that the results obtained could reach not only the research world but also the productive world agricultural and mechanical entrepreneurs, and the agro-bio economy industry on the whole..

Panacea Project

Researchers opted for scientific communication such as scientific articles in specialised journals, technical publishing publications, but also conferences, meetings with industry or agricultural organisations, seminars, training courses for technicians, and especially a website on which all the innovations produced were uploaded

Within the scope of the Panacea project there were 322 scientific publications both in Italian and in English.

The project has produced a very important bibliographical offer that is made available to the stakeholders through the project website **http://www.gruppo- panacea.it/biomasse/**.

In the web site the publications are reported by category, according to the type of cultivation (woody crops, annual herbaceous plants, perennial herbaceous plants, agricultural residues) and according to the subcategory agronomy, mechanization or post-harvest).

In the Agronomy sub-category, the best cultivation techniques, the results related to the varietal tests of all the species considered in the Project, the productive results in relation to the different crop paths and the genetic improvement carried out, are reported. In the Mechanization sub-category, the results of the performance and quality of work of the prototypes developed, the description of the technological innovations reached and the innovative mechanical systems produced are reported. In the post-harvest sub-category, the results obtained during the storage tests of the harvested biomasses, both for energy crops and for agricultural and forestry residues, are reported.

Furthermore, since the translation of the contents into English has also been foreseen, 46% of the site's visitors are of foreign origin, both European and especially from developing countries, both in the Asian area (Philippines, India, and China etc) and South America (Costa Rica, Cuba, Mexico, Peru, Dominican Republic Santo, etc).

Certainly, in addition to the downloadable articles in English, the site was consulted especially for the Prototypes section in which movies of the machinery developed within the Project are available.

In addition, three agro-energies Experimental Demo Centres were set up in Italy, with the dual objective of fostering the dissemination of technological innovations to the end users and meeting the different actors of the agro-bio-economy chains (industry, mechanical companies, agricultural entrepreneurs, contractors).

The Centres carry out the scientific and experimental research activities and also organise guided tours, training seminars, thematic demonstration days and, in collaboration with various universities, internships, degree theses, doctoral theses and post-graduate specialisation courses.

This Italian experience can be taken as a good practice for sharing knowledge, both because it was born from specific requests of stakeholders of the sector, and because it was conducted with a view to providing scientific technological support for the implementation of new bio-economy supply chains.

6. Conclusion

Displacement of fossil fuels is a primary driver for industrial crops, bioenergy development and bio-based economies. Phasing out contentious raw material and pollutants is also a driver for the adoption of bio-based solutions through industrial crops. Added to this, the lack of indigenous non-renewable fossil energy resources require the need for fossil fuel imports. Since agriculture is a consumer of energy, the development of agricultural based industrial crop sources from the underutilised European land base is an attractive alternative for farms and rural communities who otherwise depend greatly on non-renewable energy sources.

There is a good current knowledge base around industrial crops at present but it needs development. An important factor of any research is the effective distribution of current and upcoming knowledge to all stakeholders in a manner that is easy to understand.

7. Other relevant H2020 projects

Nefertiti- Demonstration events focus on showing and understanding innovation within a working farm context or within a local setting. NEFERTITI aims to network European farms to enhance cross fertilisation and innovation uptake through demonstration. 10 themes are addressed. **https://nefertiti-h2020.eu/**

PLAID-The project has been designed to encourage farmers and farm employees to embrace innovations in agriculture, leading to a greater sustainability of European Agriculture, by accessing high quality demonstration activities on commercial farms. **https://plaid-h2020.eu/**

FarmDemo- Aim to enhance peer-to-peer learning and focus on farm demonstration as a tool to boost innovation uptake. FarmDemo is a close collaboration of 3 European projects funded under Horizon 2020. They all aim to enhance peer-to-peer learning and focus on farm demonstration as a tool to boost innovation uptake. The FarmDemo Hub has been jointly developed by AgriDemo-F2F and PLAID. **https://farmdemo.eu/hub/**

Fairshare- Gathers an evidence base of the digital tools and services used internationally. It will enable advisors to address challenges for embedding digital tools in different advisory and farming contexts across the EU. **https://www.h2020fairshare.eu/**

AGRIDEMO The overall aim of AgriDemo-F2F is to improve understanding of effective on-farm demonstration activities. Such activities are considered as an important instrument to enhance farmer-to-farmer learning, and to connect farmers with other actors, in order to support and further develop innovation in agriculture. **https://agridemo-h2020.eu/**

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eip-agri
AGRICULTURE & INNOVATION

The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on:
http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf

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