Ref. Ares(2023)7957933 - 22/11/2023

BIKE

BIOFUELS PRODUCTION
AT LOW - ILUC RISK
FOR EUROPEAN SUSTAINABLE
BIOECONOMY

D 6.3

Exploitation of lessons learnt

Dissemination level: PU

Date 08/09/23

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 952872

Document control sheet

Project	BIKE – Biofuels production at low – Iluc risK for European sustainable bioeconomy
Call identifier	H2020-LC-SC3-2020–RES-IA-CSA
Grant Agreement N°	952872
Coordinator	Renewable Energy Consortium for Research and Demonstration (RE-CORD)
Work package N°	6
Work package title	Good practice case studies and lessons learnt for market uptake
Work package leader	RE-CORD
Document title	Exploitation of lessons learnt
Lead Beneficiary	CRES
Dissemination level	PU
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Reviewer(s)	All partners
Issue date	8 September 2023

New version submitted: 22/11/2023

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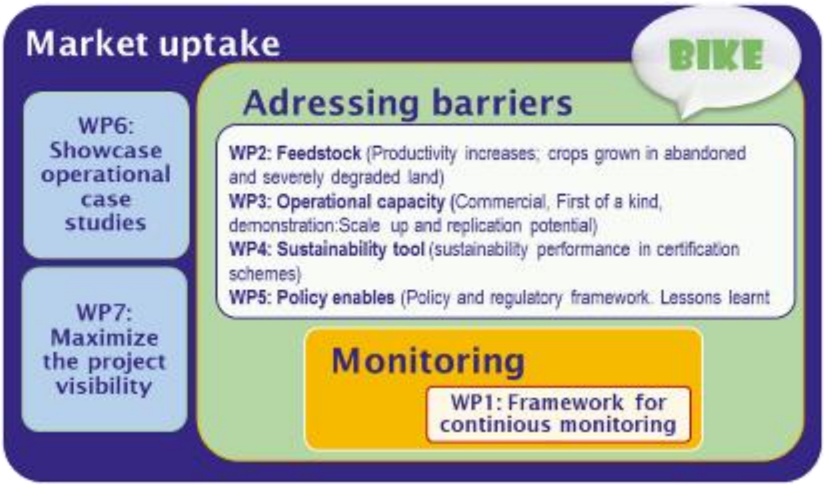
Executive summary



BIKE aims to propose scientifically robust solutions that will facilitate the wider uptake of low ILUC risk biofuels, bioliquids and biomass fuels by the transport sector in EU and lead to increased shares in the final energy consumption by 2030. It develops a certification module for low ILUC risk biofuels, bioliquids and biomass fuels and a decision support tool to guide policy and industry decision makers on the potential of low ILUC risk options in their country and on how to assess them. These can form the basis for more informed policy, market support and financial frameworks at national, regional and local level. The methodology applies a systemic approach through the seven Work Packages (see above graph).

1 Introduction

The main aim of **WP6** is to analyse and showcase the good practices of the case industry-led studies in BIKE, promoting their replicability at EU level, and to provide an overview of the lessons learnt for further market uptake of low ILUC risk biofuels.

The work in WP6 has been organised in four activities. In the first activity concrete profiles for the selected low ILUC case studies have been compiled (**D6.1**), in the second a SWOT analysis for the case studies of D6.1 have been carried out (**D6.2**). In the third activity they key lessons learnt from the case studies have been identified in order to be applicable to other cases throughout Europe (**D6.3**).

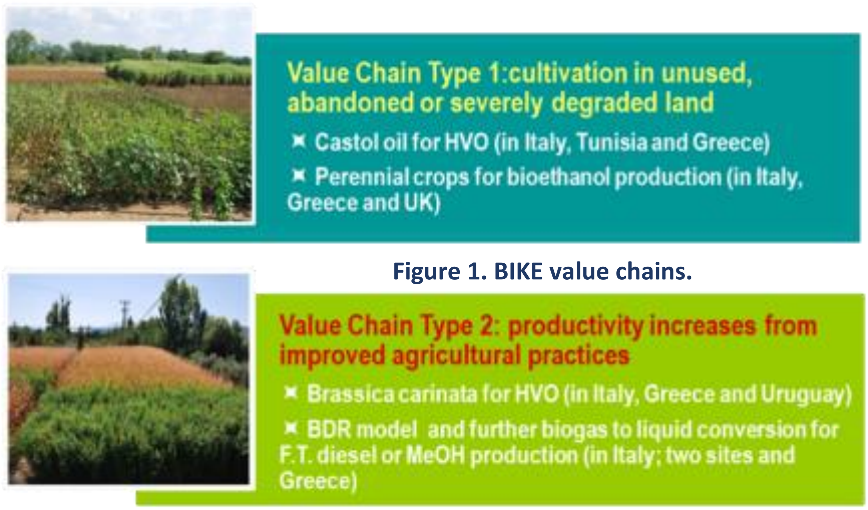


Figure 1. BIKE value chains.

Last but not least in the fourth activity open labs (open days) have been organised for the selected case studies (**D6.4**). Four open labs had been organised throughout the project lifetime. Two open labs had been organised for the first value chain by M25 (the **1st in Sardinia/Italy** for **castor bean** and the **2nd in Viotia/Greece for perennial lignocellulosic crops),** while another two dedicated to second value chain organised by M33 (**the 1st in M31 in Thessaloniki/Greece for brassica carinata and oilseeds and the 2nd for BDR model in Calabria/Italy**) (see **D6.4**).

In BIKE two value chain types are including (2.1 and 2.2); matching definition for additionality, as it is provided so far by the Commission Delegated Regulation (EU) 2019/807 of 13 March 2019 supplementing Directive (EU) 2018/2001, i) **cultivation in unused**, **abandoned or severely degraded land** and ii) **productivity increases from improved agricultural practices** (Figure 1). In D6.2 swot analysis for the case studies described in D6.1 is being performed.

1.1 Value chains produced from cultivation of feedstock on unused, abandoned or severely degraded land

These value chains analyse biomass feedstock options that can be cultivated on unused, abandoned or severely degraded land. They use as baseline the work in **Magic project** (www.magic-h2020.eu) which has characterised and analysed projections for current and future marginal lands in Europe facing natural constraints and provided a spatially explicit classification that serves as a basis for developing sustainable best-practice options for industrial crops in Europe[1] (WP2). Thereafter, the work further focus the data and assumptions used by examining additional lignocellulosic ethanol production from perennial/biannual crops (CRES, REC) feedstocks from the oil, starch and lignocellulosic categories as well as any crop management practices (cover crops, catch crops, rotation, agroforestry, etc.) that may benefit yields and soil improvements (e.g. biochar, etc.). The analysis in BIKE provides update, tailored information for feedstock production potentials (in tonnes and GJ) in Europe with disaggregation at

[1] https://iiasa-spatial.maps.arcgis.com/apps/webappviewer/index.html?id=a813940c9ac14c298238c1742dd9dd3c

NUTS2 level both for land types, suitable crops and cropping practices (WP2). Potential yield increases will also be provided based on analysis with the WOFOST and GWSI models[2]. In addition to the top down analysis BIKE is also evaluate the following Good Practice cases (WP6) for feedstock produced on unused, abandoned or severely degraded land (Figure 2):

- **Castor oil cultivation in arid/degraded/abandoned land**, with biochar production for soil improvement, for HVO production (ENI, REC)
- **Lignocellulosic Ethanol production from perennial/biannual crops** (CRES, REC)

1.2 Value chains produced crops which have increased yields from improved agricultural practices

These value chains analyse crop options that can have increased yields through improved agricultural practices. Yield increases that BIKE will examine will be the outcome of **improved crop management** (sowing, soil preparation, fertilisation, etc.); soil carbon increase with biochar, **crop rotation**; catch crops, improvements in harvest; **precision farming techniques**, etc. Except the top down analysis BIKE is also analyse the following Good Practice cases (WP6) for feedstock produced crops which have increased yields from improved agricultural practices (Figure 2):

- **Brassica Carinata cultivation as cover crop** for low ILUC biofuel production (UPM)
- **Biogas Done Right model for Biomethane production** in decentralized farms, virtually and regulatory integrated with centralized Biomethane-to-liquid conversion plants as F.T. diesel, kerosene, jet or MeOH production (CIB – REC)

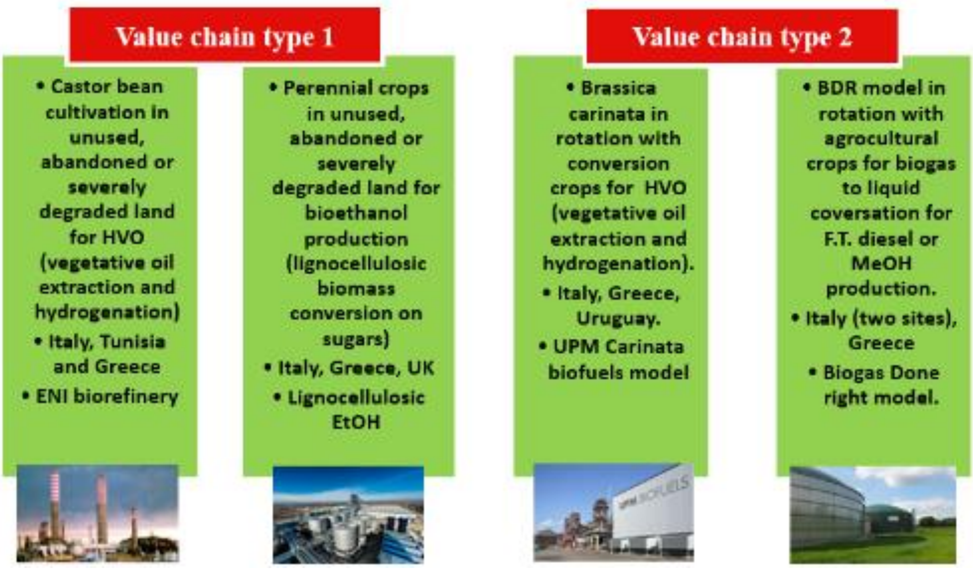


Figure 2. BIKE value chains

The aim of **D6.3** present the key lessons learnt for each four case studies (each case study including three sub-case studies) in terms of success and failures and then analyse their transferability to other cases in Europe based on the work performed in WPs 2-5. The lessons will include the complete value chain (land use, feedstock production, conversion, end use) and will also be analysed for sustainability and policy related issues. The key lessons learnt will be representing the object of the exploitation strategy. The main activity of Task 6.3. will be of promoting market uptake, getting information from WP2, WP3, WP4, and

[2] http://www.yieldgap.org/web/guest/europe

supporting WP1, WP5 and WP8 in the development of a strategic plant for exploiting BIKE outcomes for both commercial development initiatives and for future Policy Making strategies. The activity of Task 6.3. will be strongly related with task 8.3. on follow up strategy

2 CS1: Castor oil for HVO

2.1 Castor

Castor (*Ricinus communis* L., family Euphorbiaceae) is a valuable oilseed crop that can be grown either as annual or perennial. Although it is originated from Ethiopia, castor is indigenous to the southeastern Mediterranean Basin. Usually, it is grown as annual spring crop with a growing cycle from 120 to 150 days in the Mediterranean region (mid-April to mid-September). In the Mediterranean region it can be found as native species mainly in its perennial type. The colors of the plants can vary from red to green. Its panicles are racemes and each raceme (Figure 1) produces 80 to 120 capsules with 3 seeds each. The weight of 1000 seeds vary from 100 to 150 gr.

Figure 3: View of castor at several stage of growth (source: CRES; Greece).

It has been selected by MAGIC project as valuable industrial crop to be grown on marginal lands facing natural constraints because it is reported as crop with tolerance to insects and diseases, nematodes, drought and heat, high and low pH, poor soil and slope. The crop can be grown on low rainfall and fertility conditions and it is considered appropriate for drying farming. It 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 than 15°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. At flowering and capsule formation stages high rainfalls have negative effects since they help the appearance of botrytis disease. 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.

In MAGIC project (www.magic-h2020.eu) it had been grown successfully on marginal and on contaminated lands. When it was grown on marginal lands the seed yields varied from 2-3 t/ha. When it was grown on contaminated lands with heavy metals it was found that castor accumulates Pb and Ni, while it was excluder of Zn and Cb. It was also found that castor bean tolerates Pb, Ni and Zn. The crop has a moderate tolerance to salinity.

Although it has been considered as a crop with great importance for the marginal lands in the Mediterranean region, it can be found mainly on demo fields. It is a commercial crop in India, China and

Brazil. Its world cultivation area is higher than 3 million ha with a total oil seed production of 1.8 million tones (>1.5 million tones come from India). Europe is one of the main importers of castor oil for numerous industrial applications. The last years emphasis has been given to the development of short varieties with large number of racemes per plant having as much as possible uniform ripening to support the mechanical harvest.

Figure 4: Capsules (green and dry), seeds and castor oil.

A deep ploughing is necessary, for weed control and conserving moisture followed by harrowing. For annual short type varieties, it is recommended the distances between the rows to be 1m and within the rows 25 cm and a quantity of 12-15 kg seeds/ha is needed for sowing. The soil temperature at sowing should be higher 12^0C and the soil depth at sowing to be 6 to 8 cm. The crop has an initial slow growth rate but a month from sowing the growth rate increases. that increase a month from sowing.

Although castor tolerates moisture stress it responds positively when it is grown under irrigation. When it is grown on dry areas 2-3 irrigations are needed from emergence to beginning of flowering (the most critical stage for irrigation is the beginning of the flowering phase). During the maturity phase irrigation should be avoided since it prolongs the vegetative phase and results in delayed maturity of the seeds.

Its seed yields varied from 2 to 5 t/ha with oil content to vary from 47 to 50%. It has been estimated that for 2 t/ha seeds from the soil removed: 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.

Figure 5: View of mechanical harvesting

The harvesting should be done when the capsules turn to yellow-brown (120-150 days from emergence in the Mediterranean region). Usually, the harvesting time is mid-September and for most varieties the maturity is not uniform and thus 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. Currently, prototype headers are being developed in Italy in order to fit the castor racemes, capsules and seeds. Currently, in the view of MIDAS project (www.midas-bioeconomy.eu), the value chain of castor bean grown on marginal lands facing natural constrains is being optimized. Emphasis is being given on growing improved short-type hybrids, its uniform ripening as well as in its mechanical harvest.

The oil content of castor seeds is around 48% (47 to 50%) that is higher compared to the majority of oilseeds. It is non edible and can be used for biodiesel production. Castor oil is composed mainly of triglycerides and slight amounts of free fatty acids and thus has quite low variability in terms of fatty acid content compared to the majority of oilseeds that makes it quite promising for biodiesel production.

Castor oil is quite rich (85%) in ricinoleic acid (12-hydroxy 9-octadecenoic acid) and has very small quantities of non-hydroxylated fatty acids such as oleic, linoleic, palmitic, stearic, and linolenic acids. Thus, castor oil has 7 times higher viscosity compared to other vegetable oils and make the best biodiesel by blending with fossil diesel. Its high content of ricinoleic acid gives to castor oil the possibility to be used for more than 700 uses (chemical and medicinal) in the international market. Castor oil is mainly used for lubricants, but also for polymers such as polyurethanes. It has a history of more than 50 years in the production of Polyamide-11, also known as Rilsan-11. More recently, castor oil gained interest for the production of sebacic acid, which can be used as a monomer or to produce solvents. Europe is the main world user of castor oil, presently the only commercial source of hydroxy fatty acids (HFA), consuming almost a quarter (150,000 tons per year) of the entire world production. The castor meal has high protein content of 34-36% that can't be used as protein supplement because it contains several toxic compounds.

3.2 Castor case studies in BIKE

Kenya, Makueni country by Eni (audit)

- **200 ha distributed in 44 villages. KALRO institute and University of Bologna support this project started from 3 varieties, rotations with other oilseeds. Seed yields 1.5 to 2.5 t/ha with oil content 45-50%. Mechanical cultivation is now always feasible in Kenya.**

Italy, Sardinia by Eni (with Bonifiche Ferraresi)

- **Several varieties and densities tested in 2021 & 2022, better yields had been recorded in the high density fields (seed yields of 2.6 t/ha with density >1 plant/m2 in 2021). In 2022, three varieties compared in plots with high density (almost 2 plant/ha) and an demo harvest was organised with a innovative header (Fantini).**

Greece, Velestino by CRES (with University of Thessaly)

- **In 2021 & 2022 an 1ha abandoned field cultivated under no-tillage. C1012 variety was imported by Kaiima company. High plant density was applied (>4 plants/m2). The no-tillage worked very well. Herbicides applied at the end of August to stop growth. Harvesting trials was done with existing machinery but additional actions is needed. Seed yields between 1.5 & 2.5 t/ha.**

Three case studies based on castor bean on unused, abandonded or severely degrated lands have been developed and studied as listed below. The 1st was developed by ENI in Kenya and it was used for audit, while the other two was carried out in Europe; in Italy by Eni and in Greece by CRES.

In all case studies the project partners collaborated with regional stakeholders (industries, research entities, local and national authorities) and a number of cultural practices have been compared/applied (like varieties, sowing dates/practices, plant densities, low inputs irrigation and fertilization protocols, harvesting methods). In the case study of Kenya (arid and semi-arid) the area of the demo trials was 200 ha with quite ambitious plan to be further gradually expanded to 15.000 to 20.000 ha. It should be pointed out that the mechanization of the cultivation it was depending on the farmer's capacitities. Thus, there were castor fields with mechanized plouging and other with animal-drawn ploughing, or manual hoeing. Recommendations on how to grow castor bean was provided to the farming cimmunity in order to ensure the good establishment and devlopment of the crop.

In the case of Kenya three locak genotypes have been grown, while in Greece and Italy high yielding hybrids imported from Kaiima company have been also grown. Based on the case studies it can be said that a plant density of 4000 plants/ha should be targeted and the needed seeds per ha varied from 12-15 kg. In the majority of the case studies uniform ripenning was recorded.

In the case of Italian case study a uniform ripenning was recorded and during the 1st BIKE open lab a demo harvesting of castor had been organised using a prototype header developed by an Italian company.

In Greek case study showed that no tillage sowing could be applied for castor bean but lower yields could be expected compared to fields that reduced and/or convetional tillage had been carried out. In the same study four herbicides to stop growth and organise the final harvest and two conventional harvesting machines had been compared. It should be pointed out that in Greece biodiesel is mainly produced by rapeseed and sunflower and the biodiesel companies are currently looking for low ILUC feedstock from crops like castor bean growing on abandoned, unused and/or contaminated areas. In the area of the field trial there is a biodiesel plant using rapeseed and sunflower for biodiesel production.

The ENI's project in Kenya (Figure 6) had two main targets:

- The production of **low ILUC vegetable oils** to feed Eni's biorefineries in Italy (Gela and Marghera) in the short term and in a longer-term the locally valorization by the conversion of the Mombasa refinery into a biorefinery supplied through the collection of used cooking oil (UCO); Castor oil has been validated for Eni HVO proprietary technology.
- The **development of agri value chains** where castor was included.

MAKUENI AGRI HUB (Base foundation, Jan 2022) | MAKUENI AGRI HUB (HSE Induction, Feb 2022) | MAKUENEI COUNTY (Demo fields, Jan 2022) | KADJAGO COUNTY (Stekeholder engagement, Feb 2022)

Figure 6. Photos from the castor bean case study in Kenya.

An **Agri Hub** had been set up to act as an aggregation and processing center to produce oil and residual cake. This center also offers services to farmers community by providing guidelines on mechanization, cultivation protocole (sowing, seeds, fertilizers, etc.) and by training. The business model adopted on local farmers for oil seed production and ensures the market access, whether they are smallholders, cooperatives, or large companies, through the formalization of a contract for seed supply (contract farming). The processing for the oil extraction will be performed through the creation of collection and processing centers (so called Agri Hubs).

Based on ENI's activities in Kenya it was confirmed that the castor cake can be used as **soil enricher** (NPK 5-1-1). It should be pointed out that the seed cake is the 50% of the seeds weight having a residual oil content of 5-7%. Eni is also studying the possibility to convert the residual biomass into biochar via slow pyrolysis, to be reintroduced in the soils as carbon farming measure. This additional practice may be accounted in the overall LCA of the biofuel produced or accounted separately with creation of a carbon project under a voluntary scheme.

The model has a great impact on the Sustainable Development Goals (SDG) and it is based on the "Just Transition" principles, focusing onfive pillars: food security and health, jobs and rural income, economic development, access to land, territorial regeneration. Overall, the initiative in Africa aims at providing job opportunities and creating income for a large number of families in several countries.

The proposed approach has **multiple values**; the creation of a different energy mix in Africa and reduction of fossil fuel consumption, creation of socio-economic development and rural income from agro-industrial activities, diversification of agriculturalactivity and poverty reduction, in consistency with the values expressed by the SDGs. Starting from 2022, the project will enter into a production phase, with the implementation of all measures to ensure the compliance to ISCC-EU certification model.

The case study refers mainly to European legislation on biofuels. In particular to the REDII renewable energy policy. The Project focuseson the production of "low ILUC-risk biofuels" as defined in the Recast Renewable Energy Directive. They are fuels produced in a way that mitigate Indirect Land Use Change (ILUC) emissions, either becausethey are the result of productivity increase (agricultural rotations and intercropping) or because they come from crops grown on severely degraded land.

The case study (Figure 5) will eventually contribute to generate knowledge for the development of carbon negative initiatives in Europe, such as Carbon Farming. The program is in line with the national Kenyan policies and, in particular, with the National Bioenergy Strategy 20-27 in which the castor is indicated as feedstock with high potential for cultivation inthe country.

The main ***lessons learnt from castor value chains*** are:

- Castor bean is a non edible crop multipurpose crop with high potential for both LOW ILUC biodiesel production and bio-based applications (seedcake as soil enricher and the residual biomass for biochar production as soil amendment) supposrting the biorefinery concept.
- Seed yields between 1.5 to 2.5 t/ha with oil content 45-50% have been confirmed. The management practices (like improved varieties, densities, mechanization of the crop) can be improved as well as the farmers experience to grow the crop and thus higher yields could be expected.
- It can support regional agri-value chains (agri-hubs) offering farmers and additional income source.
- It is in fully accordance with RED II and SDGs and low carbon farming.
- Castor bean can be also cultivated on contaminated lands (heavy metals and/or organic pollutants) that are appropriate for food and feed production. In these lands competition with food will be avoided and phytomanagment strategies to be supported.

3 CS2: Perennial lignocellulosic crops for advanced biofuels

3.1 Miscanthus

Miscanthus × giganteus (*Miscanthus sinensis* x *Miscanthus sacchariflorus,* family Poaceae) is a perennial sterile perennial grass with a lifespan up to 20 years or more. It is sterile and multiplied by rhizomes, stem cuttings or small plants. It develops a deep root system and can do up to 1.2 m deep in the ground. It develops stems with height 2.0 to 3.5 depending on the lifetime year and the site of the cultivation (Figure 7). The plant develops new shoots on a yearly basis in spring and reaches its pick height at the end of the summer time, while the harvesting time takes place annually during the winter where the majority of the leaves have been fallen. At that time the moisture content is decreased to 40%.

Miscanthus is originated from East Asia and has been introduced to Europe in the decade of 30's, initially as an ornamental cultivar and at the of 60's it gained attraction as fiber source for building materials and later on as biomass crop due to its high productivity even on marginal and/or degraded lands. It has been selected by the majority of EU research projects as a key biomass crop (OPTIMISC, OPTIMA, MAGIC, GRACE, BIOENERGY CHAINS, etc.). The total cultivation area in Europe is around 25.000 ha located mainly in UK, Germany, France and Italy.

Figure 7: a) early stages of establishment year, b) regrowth (April 2013), c) flowering phase (September 2014) and d) harvesting time (January 2022)

Miscanthus has limited restrictions for soil types and soil pH, so that can achieve high yields in a variety of soils but prefers soil with drainage, while the preferred pH range is from 5.5 to 7.2. As for the climate conditions, Miscanthus is a highly tolerant plant, that can remain unaffected when the average irrigation level is around 440 mm, when are properly distributed throughout the cultivated period. Maximum yields of Miscanthus are recorded with precipitation levels ranging from 720 to 900 mm. The preferable elevation of Miscanthus is an average of 400 m above sea level and a minimum temperature of 6 ºC to ensure survival of new shoots, if the temperature drops below minus 9º C there can be damage in its root system.

The establishment of miscanthus should be done from March to May depending on the site of cultivation. As mentioned, the most common way of establishment is by rhizomes with a cost of around 2100€/ha that represents the 75% of its production cost.

Figure 8: a) non irrigated plots, b) irrigated plots

Miscanthus is considered as quite promising biomass crop for both marginal and/or contaminated lands. Although the irrigation is not crucial for Miscanthus (Figure 8), at the establishment year some irrigation is needed for the successful establishment of the rhizomes. It has been estimated that the 65% of the total water needs are during the summer. In terms of fertilization, several research works showed a strong correlation between N and increased biomass yields.

As perennial grass, miscanthus should be harvested annually during the winter time and in some areas in the north of Europe till the beginning of spring and the expected yields on marginal lands can vary from 10-20 t/a dry matter yields annually. It is suggested to be harvested after a killing frost in order the moisture content and the ash content to be as low as possible, the nutrients to return to the rhizomes and the leaf fraction to be as low as possible. This can be expected from late December in the south of Europe till the early spring in the north.

There are no specialized harvesting machines for miscanthus, so harvest is usually conducted by conventional means usually adapted in order to process its height and stem hardness. After harvest Miscanthus can be fragmentize by a combine harvester or balled with density of up to 140 Kg/m^3. Concerning the storage, if Miscanthus is balled, the usual storage guidelines follow the ones used for grain, but if fragmentation is performed then Miscanthus is treated like corn. In case of long-term storage, moisture content must be below 13%, otherwise there is a great chance of mold grown in harvested material.

Miscanthus is considered as valuable feedstock for low ILUC biofuels (advanced biofuels) grown on marginal, unused and/or degraded lands (like projects GRACE, OPTIMISC, OPTIMA, MIDAS) as well as on contaminated lands with inorganic and organic pollutants (like projects GRACE, GOLD, CERESiS, Phy2Cliamate). Miscanthus feedstock had an ash content that did not exceed 3% and it's the lowest values recorded among all tested perennial grasses. Apart from energy and biofuels production, miscanthus is used as feedstock for biobased products (composites, building materials, etc.).

3.2 Switchgrass

Switchgrass (*Panicum virgatum* L., family Poaceae) is a C4 warm-season perennial grass with a lifespan 10-20 years depending on the area of its cultivation. It is established by seeds having a wide range of varieties grouped in lowland and upland ones. The plant has erect stems with a height vary from 0.5 to 2.7 m (Figure 9). At the inflorescence open panicles 15 to 50 cm long are being developed on the top of the tillers. Switchgrass plants have a deep root system that can be up to 3 m depth.

Switchgrass is native of North America and thus it is considered as New World species, where it occurs naturally from 55°N latitude in Canada southwards into the United States and Mexico. 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.

Figure 9: View of switchgrass several stages of growth

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. European research confirms that lowland ecotypes could yield more than upland ones when grown in the pedoclimatic conditions of the South Europe.

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).

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^{0}C. 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 has been reported that much of eastern North America is highly suitable for switchgrass production, while areas with Mediterranean climate like California is unsuitable without irrigation. In terms of fertilization, it has been found that N is the most limiting nutrient for switchgrass. In switchgrass the final harvest takes place in winter (after a killing frost) and some nutrients have already translocated to underground tissue.

Figure 10: View of switchgrass ready for harvesting

Yields up 20-24 t/ha have been reported on annual basis with 20-30% moisture content. Usually, the yields maximized in the 2^{nd} or the 3^{rd} 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 relatively 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.

The harvested biomass has a Gross calorific value (MJ kg-1) 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 3.8 to 5.4%. 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.

3.3 Case studies on Perennial lignocellulosic crops

Three cases on perennial grasses have been studied in BIKE; two of them focus on miscanthus (UK and Italy) and one on switchgrass (Greece) while one of them was used for audit (UK). The three case studies are listed below:

Miscanthus in UK located in Taunton (own to Miscanthus Nursery Limited, Lower Marsh Farm), 95 ha of miscanthus, established by rhizomes at three time frames, a spring harvest is being carried out annually, the feedstock produced used for biofuels, animal bedding and biocomposites.

1 ha switchgrass field established in 1998 and maintained for 22 years, harvesting annually at the end of January, lowland and upland switchgrass varieties cultivated, the distances between the rows were 15 cm, the mean yields of 22 years was 11 t/ha, ceiling yields were recorded in the 2nd and 3rd growing period up to 20 t/ha.

A 3 ha miscanthus field was established in Italy (Lombardy), it was used the hybrid Miscanthus X Giganteus for the field establishment, the case study was established by Planeta Renewables s.r.l., irrigation needed only at the establishment year, the annual dry matter yields varied from 20 to 25 t/ha.

In all case studies the field trials had been estbalished on abandoned field trials. Miscanthus established by rhizomes, while switchgrass by seeds. When miscanthus grown in UK the harvested was delayed every year till spring, while in the south (Italy) was done within the winter time. Switchgrass in Greece was annually harvested at the end of January.

UK case study was used for audit within BIKE. The total area of miscanthus in UK had been established at different timeframes. The low ILUC feedstock in this case study was used for biofuels production as well as feedstock for animal bedding and biocomposites. There are 25 suppliers and the harvested biomass is directly transported to the buyers. The company has no storage facilities for the harvesting biomass.

In all case studies the soil carbon was improved after the cultivation of the perennial grasses. Irrigation was needed only in the case of switchgrass (Greece) and of miscanthus (Italy; only at the establishment year).

Usually, all perennial grasses give the ceiling yields from the 2nd till the 5th growing period and there after the yields reduced and stabilized for a period of around 8 to 10 years. In the case of switchgrass trial the yields maximized in the 2nd and the 3rd growing periods with yields around 20 t/ha, while at the establishment year were around 10 t/ha. It should be pointed out that the last years before the plantation completion (years 20 to 22) the yields were quite low and varied from 6 to 8 t/ha.

Miscanthus productivity in the Italian case study varied from 20 to 25 t/ha with 22% moisture content. It was harvested the total biomass produced and thus no residual biomass was available. Miscanthus biomass could be stored as chips or high-density bales. Handling could be conducted using telescopic forklifts normally used into straw handling or silage management.

The main ***lessons learnt from castor value chains*** are:

- Perennial grasses (miscanthus and switchgrass) are high yielding lignocellulosic crops that produce feedstock for advanced low LUC biofuels with annually dry matter yields up to 20 t/ha (mean yields of the crop lifetime > 10 t/ha).

- Miscanthus having higher production cost compared to switchgrass since it has to be established either by rhizomes, stem cuttings or plants. There are companies in Europe providing either rhizomes or plants. The higher cost establishment for miscanthus should be considered by the farmer. The fact that miscanthus is not established by seeds is an issue. Actually, in Europe we are totally depended on a sterile genotype. In terms of switchgrass, some problems on seeds supply in Europe have been detected.
- Its mechanical harvesting is well organised and existing harvesting machines can be used; The harvesting material can be also baled. The produced feedstock can be used for low ILUC biofuels but can be used also for biobased products.
- It is expected the soil carbon to be increased after the end of the plantation. Both of them in the majority of the studies are reporting as boosting biodiversity and play a positive role on ecosystem services.
- Perennial grasses can be grown successfully on marginal and/or on contaminated lands and there are many EU research projects that have proven this. Currently, there are three EU research projects growing miscanthus on contaminated lands for advanced biofuels production.
- When grown in the dry areas of Mediterranean region irrigation is necessary. Between the two crops, switchgrass needs almost half of the irrigation needed for miscanthus.
- At the final harvest the moisture content is 35 to 45% for miscanthus, while low values are expected for switchgrass (15-30%). Miscanthus has lower ash content (<3%) compared to switchgrass (>4%). Miscanthus had slighter higher calorific value.

4 CS3: Brassica carinata for HVO

4.1 Brassica carinata

Brassica carinata (family Brassicaceae) is closely related to rapeseed. The plant can be up to 120 cm height while it has a deep root system. It is a tall, leafy plant, well adapted in the Mediterranean climate. It can be grown either as winter or spring annual crop. Flowers are usually light yellow about 1.5 cm across, on short pedicels on an extended raceme. The fruit is a silique up to 5 cm long. The seeds are small but bigger compared to *Brassica napus*. 1000 seeds weight 3.5 grams.

It is originated from Ethiopia. Several studies have pointed out its high seed yields, its ability to adapt in arid and semi-arid conditions, its tolerance to abiotic and biotic stress and thus have been proposed it as an alternative oilseed crop to *Brassica napus* for the Mediterranean region as well as for marginal lands**.** The crop has been studied in the past in a number EU projects, while recently studied in MAGIC (2017-21, www.magic-h2020.eu) as a valuable oilseed for marginal lands and currently in CARINA project (2022-26, www.carina-project.eu) as a valuable cover crop.

Although in the past several varieties had been developed in Spain and had been tested in the Mediterranean region, commercially available in Europe are currently lucking. In the view of CARINA project some Brassica carinata varieties will be tested throughout Europe and some case on marginal lands will be also included.

Figure 11: View od Brassica carinata at several stages of growth (source: UPM)

It is well adapted to the temperate climatic zones of Europe. The crop is characterized by high tolerance to heat and drought and saline conditions, but has not resistant to frost. In the Mediterranean region the crop can be grown both as winter and spring crop, while in central and north Europe should be grown as spring crop. The crop is suited to a wide range of soils and pH should be 5.5 – 8.0. The crop is sensitive to salt and the seeds may not germinate in soils with an above average salinity level adding that is not tolerant to waterlogging.

It has more or less the same enemies and diseases with rapeseed. The crop is susceptible to black rot (*Xanthomonas campestris*), and black spot (*Alternaria brassicicola*), and to damping off and seedling root rot (*Rhizoctonia solani*). The best disease control is the proper management rather than a spraying regime with agro-chemicals.

The soil preparation and sowing is quite similar to *Brassica napus*. For a good establishment a plant rate of 200 seeds per m^2 is recommended (8 kg seeds/ha). The sowing depth should be 1-2 cm and the distances between the rows should be 30 cm. Sowing date has been found to have a much larger effect on yield than seed rates and, where environments allow, an early autumn sowing is likely to achieve best results.

It responds well to organic manure of up to 20 t/ha. Most farmers find it easier to incorporate chemical fertilizers in the plant beds at the rate of about 100 kg N and 30 kg P. Higher levels of nitrogen will increase proteins and enhance leaf production, whereas more phosphorous will enhance the seed production potential.

The average yields have ranged from 2t/ha up to 3t/ha in Canada. It can be said that seed yield of 2.5 t/ha could be expected with oil content around 40%.

Harvest is a critical operation and losses can be heavy due to the small seeds and because the growth habit prevents all seeds in a crop maturing at the same time. Furthermore, early harvesting can reduce seed quality and late harvesting can enhance pod shuttering. The moisture content of *Brassica carinata* at harvest time of the seed must be around 7-9% and it's recommended for safe storage of rapeseed to be dried to less than 9%.

It is usually cultivated for its oil that is rich in erucic and linoleic acids and well-indicated for biofuels. Most of the literature on the energy uses of Ethiopian mustard focuses on the production of biodiesel and bioethanol. The oil profile of zero erucic-acid *Brassica carinata* consists of 33% oleic, 37% linoleic and 21% linolenic acid. The oil finds wide application in the production of water repellents, waxes, polyesters and lubricants. Seed cake that remaining after oil extraction can be used as fertilizer or feed stuff. It is also used as a green fodder crop, green manure and as a cover crop. Interest in this species for industrial uses has been increasing thanks to the particular acid composition of its extracted oil. The oil has limitations for cooking because of high contents of glucosinolates and erucic acid.

4.2 CS with Brassica carinata

Three case studies with Brassica carinata have been studied in BIKE as presented below:

- A total cumulative area of 50.000 ha established by UMP in Uruguay since 2015 (UMP)
- Field trials established in Italy (Sicily) in the view of ERICA project (RECORD)
- Demo fields established in Greece (Thessaloniki) in the view of MIDAS project, while several field trials had been carried out in the past (CRES).

The case study of UPM had been used for audit. In Uruguay carinata was grown as one of the winter crop in a rotation with summer crops soy and maize. The adding carinata as new crop to the rotation mitigates disease and insect risks. Moreover, it replaces non productive cover crop or fallow in the winter rotation.. No irrigation was applied in all case studies. The cultivation protocole is similar to rapeseed. The farming community can use same machinery with convetional crops (wheat, barlet and soya) the same machinery for its cultivation. In south Europe can be grown both as winter and spring crop, while in central and north as spring crop. High seed yields (up to 2.7 t/ha) had been recorded in all case studies with oil content varied from 38 to 42%. Residual biomass 6 to 10 t/ha can be collected. The seed meal could be used as animal feed (high protein content).

Brassica carinata provides non-edible oil suitable ~~also~~ for chemical industry uses. Fatty acid chain lengths optimized ~~especially~~ for aviation fuel purposes. Currently, the oil has been commercially processed to conventional biodiesel with the following pathway: harvesting, cleaning and drying, crushing, neutralization and pre-treatment of oil, esterification. The residual biomass from the grain (after crushing) has been used for bioenergy. Other biomass than the grain has left into the field. The process was certified. Carinata production is certified under RSB EU RED and the rest of the supply chain is also certified under EU Commission approved voluntary schemes (final fuel is EU RED compliant).

The main ***lessons learnt from castor value chains*** are:

- Brassica carinata can be grown as cover crop and can be inserted to the existing cropping systems and mitigates disease and insect risks on them. It has similar growing cycle with rapeseed. Its growing cycle is not considered as short one. It should be pointed out that shortest growing cycles had been reported by other oilseeds (camelina and crambe).
- It can be grown successfully even on marginal (saline) and/or contaminated sites, although in BIKE was not tested as such. It is considered as feedstock for low ILUC biofuels production either on marginal lands and/or rotation schemes for productivity increase. Thus, it can fit to both main value chains of BIKE (as these described in RED II).
- Seed yields up to 2.7 t/ha have been recorded in the BIKE case studies, while the oil content was around 40%.
- The crop is fully mechanized and the existing machinery for the arable crops can be used.
- The crop has similar enemies and diseases with rapeseed and thus this should be carefully considered.
- There are not sufficient varieties available in the European market to grow. Currently, reserach activities are being carried out by CARINA project where a number of carinata varieties will be tested throughout Europe as cover crops on both typical agricultural and marginal lands.
- It produces many flowers and considered friendly to the pollinators.

- The case study of carinata is fully supported by Renewable Energy Directive, Fuel Quality Directive, local agricultural policies, EU import policies.

5 CS4: BRD model for liquid biofuels

5.1 Sunn hemp

Sunn hemp (*Crotalaria juncea* L., Fabaceae family) is an annual herbaceous short-day plant with erect fibrous ridged stems. It is the fastest growing species of the genus Crotalaria. It is considered multipurpose crop and can be used green manure, fiber and animal fodder crop. The leaves are simple, up to 12 cm long and up to 3.5 cm wide, oblong lance-like in shape, covered with short, downy hairs, and arranged spirally along the stem. The plant has a strong taproot with well-developed lateral roots. Its stems develop branches when it is grown at low plant densities. Flowering starts eight weeks from sowing can it is grown in areas with short days. Deep yellow flowers developed that having the typical scheme of the Fabaceae family.

Sunn hemp is native to India and Pakistan, while in Europe can be found as alien crop. In Southeast Asia, sunn hemp has been grown as a green manure crop for centuries and now is cultivated in many tropical and sub-tropical regions worldwide. The main seed producers are: India, Hawaii, Colombia, and South Africa. In 2017, the area of cultivation for sunn hemp was 31500 ha. In USA, sunn hemp has been grown as summer cover crop that could not produce seeds since as a short-day crop delay flowering initiation till the beginning of September. Sunn hemp has been selected as potential biomass crop in the framework of Becool project (Figure 12) and thus research trials have been established in Italy, Greece and Spain.

Sunn hemp is a self-incompatible plant. Most of sunn hemp cultivars have originated from selection of improved types suited to specific localities, rather than by breeding procedures. These selections generally focused on early maturity, improved fiber yield, and resistance to pests. More recently, genetic research and breeding procedures have been conducted on sunn hemp in Brazil and India. In these breeding programmes it had be found that the final plant height and basal stem diameter are positively correlated with total stalk dry matter, indicating selections for these traits could result in higher yielding cultivars.

Sunn hemp grows well at mean annual air temperatures from 20 to more than 38^{0}C. High temperature with moderate humidity is preferable for sunn hemp growth and development. Growth may be slowed by cool weather, and the plant is susceptible to freezing injuries when the temperature is less than -2^{0}C. Although sunn hemp tolerates poor fertility soils and no fertilizer is necessary, its productivity is enhanced on fertile soils. Sunn hemp can grow well in soils with pH ranging from 5.0 to 8.4. This plant is adapted to well-drained calcareous soils and acidic sandy soils, but not to water-logged or saline/sodic soils. Sunn hemp is considered as drought tolerant and, generally, but irrigation is needed when grown on arid or semi-arid areas.

The soil must be prepared in such a manner that favors an adequate settlement of cultures, by using either appropriate equipment in the right period, taking into consideration that land preparation is one of the most important aspects for germination. Loose soil must be obtained, which will allow us to have an adequate sowing depth. A piece of information that must be taking into account is the sowing surface, the adequate surface must have 1 cm of soil depth. At greater seeding depths, emergence is poor. Seeds should be sown in soil temperatures greater than 20°C for successful germination. Seeds usually germinate readily within 3 days, and seedlings rapidly develop a dense ground cover. To establish as a cover crop, sunn hemp should be sown at a rate of 10 to 40 kg seeds per ha. Lower seeding rates can promote lateral branching. Seeds can be inoculated with cowpea inoculant to improve nitrogen fixation. The soil depth should be 2-3 cm.

It is worth mentioning that the *Crotalaria juncea* is one of the legume families; therefore, having an intrinsic capacity for the fixation of nitrogen in the soil, an action that is carried out by receiving CO2 from the atmosphere and transforming the same into nitrogen through the fixation of the same in its roots. The fixations of nitrogen, as well as the creation of organic material and the reduction of the nematode population in the soil are their main characteristics, which make the *Crotalaria juncea* a green fertilizer used internationally. In its fodder use, in which the purpose is to obtain the best possible performance, in order to obtain the highest fertilizing production, as all other cultures, which must be taken into consideration. The applied fertilizers should be not rich in nitrogen and with high phosphor and potash levels.

Field tests indicate that sunn hemp can produce 800 to 2200 kg seeds/ha when seeded in narrow rows with a grain drill. Sowing it in wide rows has been found to produce lower seed yield.

The harvesting time is depends on the end use. When it is grown for its fiber the harvesting should be done at the flowering stage (mid-September for Europe). When the crop is cultivated for green mature the harvesting should be done two months from emergence when the plants begin to flower as it decomposes more rapidly and it will have a positive N balance at this stage. As forage crop sunn hemp should be harvested up to four times under favorable growing conditions during its growing cycle; the first 6 to 8 weeks from sowing, and thereafter every four weeks. It has been recommended to sun-dry sunn hemp foliage prior to feeding animals as they do not eat fresh sunn hemp. When sunn hemp has been harvested for fiber, the top portion of the stem is used for fodder or hay after mixing with paddy straw.

Harvesting can be done by hand or with a mechanical harvester. The top portion of the plants is chopped off soon after harvesting for use as cattle fodder. The main portion of the stem is left to dry on the ground during 1 to 6 days, depending on places, so that it shed its leaves and becomes ready for retting. In some areas, stems are left up to 15 days on the ground and retting occurs naturally thanks to morning dew.

Figure 12: View of sunn hemp; a) 2-leaves stage, b) three weeks from emergence, c) first flowers, d) full flowering in mid-September, e) plantation ready to be harvested (source: CRES).

Seeds can be easily harvested with a combine when most of the pods (about 70-80%) are mature. Seed maturity can be recognized by the rattling sound of the seeds within the pods. When seeds are mature, they fall to the lowest end of the pod, thus shaking the plant will produce a rattling sound. If needed, defoliation of the plants can be accomplished by spraying with a mixture of gramoxone and sodium chlorate or with a 50% solution of liquid nitrogen. Plants can be harvested with a combine with a standard header (grain platform) that needs to be raised to reduce the amount of straw going in. Concave clearance and cylinder speed need to be adjusted as needed depending on the crop conditions.

The main uses of industrial hemp are green manure, animal feeding, and fiber and seed production. In India, clothing, twine, and rope are made from the fiber of older, densely grown plants. In some areas, seeds are fed to pigs and horses without adverse effects. However, since some sunn hemp varieties contain moderately toxic levels of pyrrolizidine alkaloids, sunn hemp fodder and seeds are usually provided as no more than 45% of the feed ration of ruminants, swine, and horses.

5.2 Biomass Sorghum

Sorghum (*Sorghum bicolor* L.) is an annual herbaceous spring C4 crop with erect stems that can reach 5 m height (Figure 13). The stems are large with a diameter up to 5 cm and are consist of alternating nodes and internodes and each node supporting one leaf. Each stem can produce up to 30 leaves (30-35 cm long and 1.3-15 cm wide). At the flowering one panicle is being developed on the top of each stem. The panicles can greatly vary in terms of color, size (short, compact, lose or open) and seed production. Sorghum has an extensive and deep root system with three types of roots: the primary, the secondary and the brace or buttress roots. The primary roots develop from the radicle and after their senescence the adventitious roots are being developed from the underground nodes and can extend up to 2 m depth. Adventitious roots are small and uniform and are supply nutrients to the plant. The brace roots develop from the root primordia of the basal nodes above the ground level. These roots provide anchorage to the plant. The weight 1000 seeds are 13-14 g.

It is originated from Africa. It was first domesticated in Sudan, Chad and Ethiopia and then it was spread first to India and China. Since the late 1980s, sorghum (sweet and fiber) had been included in several EU research projects since late 1980s. The most recently completed project is SWEETFUEL project in which countries outside EU participated (India, South Africa and Brazil). Currently, in the view of BeCool project, sorghum has been included in the lignocellulosic crops that could be used for second generation biofuels (low ILUC feedstock). There several groups of sorghum but here we focus on biomass sorghum producing biomass with high lignocellulosic content.

Biomass sorghum genotypes aroused the researchers interest due to its remarkable yield potential even when grown on marginal lands. Sorghum can be grown at altitudes from sea level up to 1000 m and at latitudes between 40°N and 40°S. It is primarily a plant for hot climates and thus thrives best on semi-arid tropical environments with an annual rainfall of 400-600 mm. It is a drought resistant crop and thus can be grown in areas that are considered too dry for maize cultivation. The waxy layer on the sheaths and stem contributes to reducing evaporation and increase the drought resistance. Sorghum is adapted to a wide range of soils, temperatures and soil moisture conditions. It tolerates a soil pH from 5 to 8.5 and it can survive temporary waterlogging but it does not grow well in shade. Sorghum is a short-day plant, although temperatures below 20°C can delay head differentiation. Sorghum plants produce sufficient juice, total sugar and ethanol yields in fields with soil salinity up to 3.2 dS/m even though the plants receive 50-75% of the water regimes typically applied to sorghum. Therefore, sorghum may be viable as an alternative crop system under increased salinity and reduced irrigation conditions, especially in semi-saline and semi-arid fields where the irrigation water is limited during crop development.

It has similar pests to corn. In order to minimize the diseases and pest problems it is suggested to cultivate improved varieties/hybrids and to follow a proper rotation system.

The soil preparation is the same with the one followed for other spring crops (corn, cotton, etc.). The sowing for the climatic conditions of Europe should be done in spring (from the beginning to the end of April) when the soil temperature is above 12^0C. Due to its small seed dimension it needs an adequate preparation of the seedbed. The sowing depth should be 2-3 cm on heavy soils and 3-5 on sandy ones. The plant density is depending on variety, environmental conditions, earliness and varies from 110,000 to 400,000 plants/ha. The most recommended sowing distances are: 45 to 70 cm between the rows and 10-20 cm within the rows. The seedling rate is varied between 10 and 15 kg/ha.

It used to be called as camel because it survives with water supply less than 300 mm for a period of 100 days. It has high water use efficiency (WUE = 193 mm of water/kg of dry matter produced or 5.2 g of dry matter/kg of water consumed). Typically, sorghum needs between 550 to 800 mm of water (rain and/or irrigation) to achieve good yields, i.e. 50-100 t/ha total above ground biomass (fresh weight). Although sorghum is a dry land crop, sufficient moisture availability for plant growth is critically important for high yields. The major advantage of sorghum is that it can become dormant especially in vegetative phase under adverse conditions and can resume growth after relatively severe drought. Sorghum is considered very efficient in utilizing nutrients from the soil because of a large fibrous root system. However, like other crops, sorghum needs adequate nutrients to produce good yields. Profitable responses to fertilization can be expected on many soils. In places where soil fertility ranges from low to moderate, the fertilization needs are about: 100-150 kg N, 60-100 kg P_2O_5 and 60-100 kg K_2O per hectare. Nitrogen application is recommended to be done in two times: before sowing and 20-30 days after the emergence.

The grain yields can be up to 0.3 - 2t/ha when it is grown rainfed conditions (India and Africa) and 4.5 to 6.5 t/ha under irrigation (USA and Australia). The yields of sorghum can be up to 140 t/ha (on fresh basis) and 20 to 25 t/ha (oven dried).

Harvesting and logistics of sorghum differs according to the end-use (first generation bioethanol, grain and first-generation bioethanol and second-generation bioethanol). A forage harvester is being used when the cultivation aims to second generation bioethanol production. In this case, the harvesting time depends on the variety, on specific climatic conditions and on biomass demand and it could be done from late September to late October. The two most common methods for harvesting sorghums for biomass are swathing followed by baling or chopping of windrows, and direct forage chopping of the standing crop.

Figure 13: View of sorghum; i) a month from emergence, ii) brace roots, iii) at the full flowering (source: CRES; BECOOL project).

Sorghum is the fifth most important cereal in the world and an important staple food in the semi-arid tropical areas of Africa and Asia. Being a multipurpose crop and it can be cultivated, apart from grain, for: sugar juice from its stalk for making syrup or ethanol, bagasse and green foliage which can be used as an excellent fodder for animals, for gasification, for second generation bioethanol production, as organic fertilizer, for paper manufacturing or for co-generation. For developing countries sorghum provides opportunities for the simultaneous production of food and bioenergy, thereby contributing to improved food security as well as increased access to affordable and renewable energy sources. For Europe sorghum is seen as a promising crop for the production of raw material for 2nd generation bioethanol.

5.3 CS4 BDR in BIKE

In the view of BIKE two case studies for BDR model have been studies are presented below:

- The audit case study developed by CIP (Calambria in Italy) and
- Case study based on field trials that carried out in BECOOL project and continued after its project completion (Aliartos, central Greece by CRES)

The audit case study produced feedstock to feed a biogas plant belonging to CIP (Calambria/Italy). The concept was to produce biogas in a way minimizing the input resources for substrate production and mainly focuses on waste and residue feedstocks as well as secondary crops that are used to produce biogas, without impacting the yield of the primary crop. Both farm and biogas plant belongs in the same legal entity. The farm owns 250 ha and 96.5 ha used to grow low ILUC risk feedstock that was abandoned. The crops used were corn, sorghum and wheat. The marginal land used had low organic matter and was suffering by gradually desertification. A reduced tillage applied and biodigestates were applied

(200m3/ha; from corn and by products like olive paste and agricultural wastes like manure). It was found that after nine years of this rotation the oragnic matter in the soil was increased. The yields of the cultivated crops were also increased.

A rotation system have been applied in central Greece (Aliartos) which was Durum wheat – Sunn hemp – Corn. The rotation scheme was established in a typical agricultural land but with relatively low organic matter (~1%). It was found that the yields of the conventional crops did not reduce and from the same land unit higher biomass yields had been produced with the insertion of sunn hemp in a typical / conventional rotation (wheat-fallow-corn). Sunn hemp produced 16 to 18 t/ha dry matter yields.

The main ***lessons learnt from castor value chains*** are:

- BDR model can be applied on both typical and marginal lands. CIP case study was applied in an abandoned land, while CRES case study was a typical agricultural land with low organic matter.
- Two crops have been inserted in the existing rotation schemes; sorghum in Italy and sunn hemp in Italy.
- In both case studies the yields of the main crops (conventional ones) did not affect and from the same land unit higher biomass yields were produced by the insertion of the biomass crops in the time frames that in the typical rotation schemes should left fallow. In both case studies higher soil coverage was achieved compared to the traditional rotation schemes.
- At the same time the soil quality is gradually increasing as a result of the use of the biogas digestate as fertilizer in Italy and by insertion of sunn hemp in italy (sunn hemp is a Fabacea crop).
- The turning of an abandoned area to an area for low ILUC feedstock production.
- Irrigation was needed for the spring crops.
- In these rotation schemes special attendion should be given to the narrow time windows to from the harvesting of one crop to the sowing of the second.

6 Conclusions

- **CS1: Castor oil (growing on unused, abandoned or severely degraded lands)**

The crop performed well and high yields had been recorded (>1.5 t/ha seeds/ha, yields even > 3 t/ha were measured with oil content around 50%) both in Europe and Kenya. The work in Kenya is organised in agro-hubs where the farming community was training and involved. The approach was to use the whole biomass produced; oil for HVO biodiesel production and the meal as soil enricher and the residual biomass for biochar production as soil amendment. They are available high yielding hybrids but the mechanical harvest needs additional modifications to fit to the crop's architecture.

- **CS2: Perennial lignocellulosic crops (by growing on unused, abandoned or severely degraded lands).**

Miscanthus works very well in central and north Europe and there are several fields (with total area higher than 25000 ha) where miscanthus is used for bioenergy and bioproducts. In the dry area of the Med region switchgrass performed quite well (with mean yields of 20 years >10 t/ha) having quite lower irrigation needs. Switchgrass gave 10 t/ha as mean dry matter yields of 22 years when grown in Greece when grown on marginal lands but the establishment cost of switchgrass was cheaper since it is established by seeds and not rhizomes. Moreover, switchgrass in the dry areas of South Europe needs half of the irrigation needed for miscanthus.

- **CS3: Brassica carinata (as cover crop, in rotation systems with conventional food crops without replace them)**

Carinata performs well in the Med region and can fit to the existing agricultural systems with high seed yields (up to 2.7 t/ha have been recorded in the BIKE case studies) but is having a similar growing cycle with rapeseed that could risk the double cropping per year. It has also several diseases and insects that means additional chemical treatments. Last but not least, it is hard to find high yielding varieties in Europe. One company is controlled the whole breeding. As alternative cover crops two oilseed crops could be exploited namely camelina and crambe. Both of them having quite smaller growing cycle (in some cases even 30 days shorter) but lower seed yields should be expected (1-2 t/ha)

- **CS4: BDR model** (in rotation systems with conventional crops)

It worked very well in Italy by CIP company. It was tested on abandoned agricultural areas, where corn, cereals and sorghum were rotated. High yields had been recorded and the soil quality had been improved after 9 years activities. In Greece another rotation had been tested (maize-sunn hemp – wheat & sunn hemp) for biomass production and it was found that higher yields had been recorded compared to the conventional rotation system (wheat-maize that leaving the soil uncovered for around 8 months). It can said that BDR model can be applied on both marginal and typical agricultural lands and in both case the soil fertility could be increased with the selection of the proper crops and rotation schemes.

The results of this study only reflects the author's view. CINEA is not responsible for any use that may be made of the information it contains