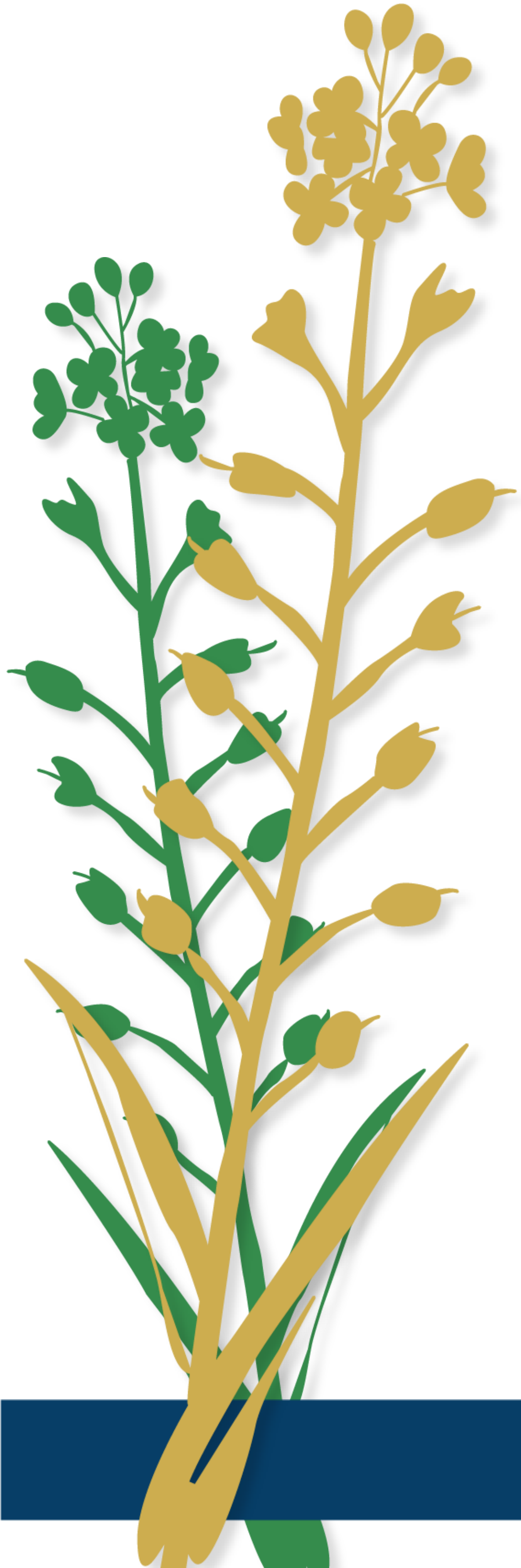
4CE-MED

Camelina:
a Cash Cover Crop Enhancing
water and soil conservation
in MEDiterranean
dry-farming systems



Methodological framework to develop life cycle thinking assessment on 4CE-MED systems

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Abstract

Cereal crops are relevant in many Mediterranean farming systems; however, there is a lack of alternatives. Conservation agriculture (CA) entails principles and benefits that could increase crop diversification while aiding in the reduction of soil erosion and nitrogen leaching. Camelina is well suited to CA systems, proven to be appropriate for commercial growing; therefore, the 4CE-MED project aims at developing Mediterranean innovative, diversified and resilient farming systems not competing for land with actual food chain by growing camelina as a cash cover crop or double crop.

Particularly, Work Package 4 (WP4) will assess the sustainability of the local tailor-made 4CE-MED systems through a robust, consistent, and science-based analytical framework. In consequence, this deliverable aims to develop a dedicated methodological framework to perform a life cycle thinking assessment on innovative oilseed Mediterranean crops. The framework proposes an assessment based on primary data from other WPs and relevant literature or secondary data, through a Life Cycle Thinking (LCT) approach composed by Life Cycle Assessment (LCA), Environmental Life Cycle Costing (E-LCC), and Social Life Cycle Assessment (S-LCA).

WP4 will select 3 countries and trials to compare the sustainability performance of current situations with the introduction of 4CE-MED crops. The cases will belong to three major camelina cropping models presented in the project: Model A introduces Camelina to replace fallow in winter cereal sole-cropping systems, in marginal areas with very dry climate, Model B considers Camelina as a double-cropping cultivation in autumn, to precede typical Mediterranean summer crops, and Model C uses Camelina as a double-cropping in late spring/early summer in colder areas to follow winter pulses (e.g. pea) or cereals harvested as fodder. The selected cases would have followed the experimental protocol presented in WP2 and will be closely linked to a Data Collection Protocol (Deliverable 4.2) to obtain first an inventory of inputs and outputs of each case.

A literature review was also conducted for this deliverable, which allowed to observe there is limited LCA, E-LCC and S-LCA studies of the Camelina crop in Mediterranean regions. Most of the information found is referred to the application of Camelina as biofuel, while some articles even highlighted that camelina is not used as food.

The definition of a goal and scope, defined in this framework expects to conduct a cradle-to-farm gate assessment with functionality based mostly on yield will be considered in culture succession is preferred. Functional unit is expected to be mass based, with derivations towards the environmental, economic and social impact categories of interest. The environmental dimension will refer to midpoint categories, with a consistent use as in most of the studies of Global Warming Potential, Eutrophication Potential and Terrestrial Acidification Potential. Regarding the economic dimension, cost categories, income and net margin will be observed, and the social dimension will include impact categories that range from endpoint to midpoint categories, where human rights, working conditions and community are to be addressed.

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1 Project background

1.1 4CE-MED Project

Mediterranean dry-farming systems mostly rely on cereal production, generally sole crop, due to a lack of other alternatives that are intensive in terms of agronomic inputs, consequently highly impacting on the environment, and vulnerable to climate change.

Conservation agriculture (CA) relies on three principals: i) minimum soil disturbance, ii) permanent organic soil cover, and iii) crop diversification. It is still not widespread among Mediterranean farmers mainly due to the limited awareness about advantages associated with its use, like the reduction of soil erosion and nitrogen leaching, and the increase of soil water availability, soil organic matter and biodiversity. In this context, the 4CE-MED project aims at developing Mediterranean innovative, diversified, and resilient farming systems, following a participatory approach, to widespread the adoption of CA. The 4CE-MED systems will include camelina, an emerging oilseed crop, as cash cover crop able to enhance soil and water conservation, while increasing farmers' revenue.

Camelina is well suited to CA systems, being commercially grown in Northern America as a no-till cover crop replacing fallow between summer crops. Camelina seeds have a high content of both protein (~30%) and oil (~40%), which increases the crop potential market uptake for food, feed (including aquaculture) and bio-based applications, due to the actual dramatic shortage of vegetable proteins and fats in Europe.

The 4CE-MED project will address all the three principles of CA: growing camelina as cash cover crop or double crop will allow increasing organic cover soil while diversifying crop rotations; moreover, camelina will be grown under no-till/minimum tillage systems to prevent soil disturbance. 4CE-MED will capitalize on a highly experienced and competent team of 11 partners located in 7 different PRIMA countries (4 EU & 3 non-EU) to fulfil its main objectives. To strengthen a multi-actor approach perspective, the 4CE-MED consortium includes research organizations, universities, SMEs, large industry, farmers' cooperatives, and farming consultants.

1.2 Work Package 4

1.2.1 General description of WP4

WP4 will assess the sustainability of the local tailor-made 4CE-MED systems by comparing them with current scenarios. It will develop a robust, consistent, and science-based analytical framework and will analyse alternative farming scenarios based on primary data from other WPs and on relevant literature and secondary data. A Life Cycle Thinking (LCT) approach will be adopted for the analysis of local ideal 4CE-MED systems in the Mediterranean study areas, composed by Life Cycle Assessment (LCA), Environmental Life Cycle Costing (E-LCC), and Social Life Cycle Assessment (S-LCA). Within this framework WP4 will also assess environmental impacts and environmental associated services, as well as economic and social impacts in the adoption of CA systems integrating the use of camelina as a cash cover crop. Based on WP2 field key parameters, the project will assess nitrogen economy (soil N-dynamics), water use efficiency, soil coverage and canopy development over time, corresponding weed incidence, monetary herbicidal inputs, crop yields and quality, complemented with results from WP4.

The general objective of WP4 is to develop an integrated sustainability assessment by:

- Developing a dedicated methodological framework to perform a life cycle thinking assessment on innovative oilseed Mediterranean crops.
- Identifying and quantifying the impacts (economic, social, and environmental) of the proposed 4CE-MED systems on the cereal-based Mediterranean agro-ecosystem.
- Maximizing the positive impact of 4CE-MED systems through the provision of objective and comprehensive information regarding the main sustainability aspects (environment, society and economy) of the planned systems adopting a robust, consistent and science-based analytical framework.

1.2.2 The objectives of Task 4.1. Methodological framework

A Life Cycle Thinking (LCT) approach for the analysis of alternative crops in the Mediterranean study areas will be developed. It will be composed by LCA, E-LCC, and S-LCA. LCA is a compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle (ISO, 2006). E-LCC is an assessment of all costs associated with the life cycle of a product, directly covered by any one or more of the actors in the product life cycle (De Menna et al., 2018). S-LCA is the tool aiming at assessing social and socioeconomic impacts along their life (UNEP-SETAC, 2009).

The first stages of this task will include the general comprehension and documentation of operations throughout WPs 1-3, to create a "data collection protocol". The protocol will include data collection tools and related basic use guidelines, responsible actors for that data gathering, calendar and guidelines for the filled instruments, among others, in close correspondence with the intended impact categories to address once inputs and outputs would be inventoried and assessed in coming tasks. This will aid in retrieving relevant information of the life cycle of the system and identify primary information availability and quality, as well as secondary information requirements. Once the framework is defined (Deliverable 4.2), as a second and final stage of this task, a validated and communicated data collection protocol with the rest of the team will be the base ground for assessment, allowing the WP to move into the subsequent tasks.

Through this deliverable: **D4.1. Methodological framework to develop life cycle thinking assessment on 4CE-MED systems**, it is expected to represent the essential structure under which the assessment will be carried out. The deliverable would be a concrete document including the functional unit, system boundaries, main impact categories and indicators, sections and processes to be followed to execute and report the results of the assessment.

2 4CE-MED cases and scenarios

WP4 will select 3 countries and trials to compare the sustainability performance of current situations with the introduction of 4CE-MED crops. This will follow a consequential approach, assessing the consequences of changing the current systems. The three locations will be selected (one per each model) according to its characterisation and case completeness. A brief description of the models in the 4CE-MED project is presented in the following paragraphs, with an example of possible cases per model to be assessed. Similarities among cases may suggest the applicability of the assessment for cases with common traits. Each selected case would have followed the experimental protocol presented in WP2 (Task, 2.2-2.3), which refers to the experimental layout (seeding rate, camelina cultivars, interrow distance), main meteorological data, soil chemical-physical characterization, as well as fertilisation, soil tillage, irrigation and weed management per trial.

2.1 MODEL A

To be developed in Tunisia, Morocco, Algeria, and Spain. This model entails the introduction of Camelina to replace fallow in winter cereal sole-cropping systems, in marginal areas with very dry climate.

2.1.1 Case 1A:

Region: Boulifa Kef, Kef governorate, **Tunisia**

Climate, geography, and demographics:

El Kef, is a Tunisia's mountainous town, located in the north-west of Tunisia, from about 175 kilometres (109 mi) of Tunis and some 40 kilometres (25 mi) from the Algerian border. The southern part of Kef (where trials will be conducted) is situated mostly in the semi-arid area, and governed by a continental climate due to its distance from the sea and very irregular rainfall, annual average = 450 mm. Climate is usually unstable, ranging from very hot summers to cold winters. Temperatures in winter are considered among the lowest in Tunisia (it can reach -6°C). Snowfall is frequent on the hills; the frosts and hail are frequent also in the late spring, while in summer plains are exposed to hot continental winds and sirocco. The extreme North West of the governorate is influenced by other bioclimates: sub-humid and lower humid characterized by a cool winter and abundant rainfall. The northern quarter of the governorate which is relatively good watered contrasts with the southern part which suffers from aridity. The governorate covers 5.081 km^2, (3.2% of the total surface of the country and about 30.7% of the North-West region surface), and presents a population of 54 701 inhabitants.

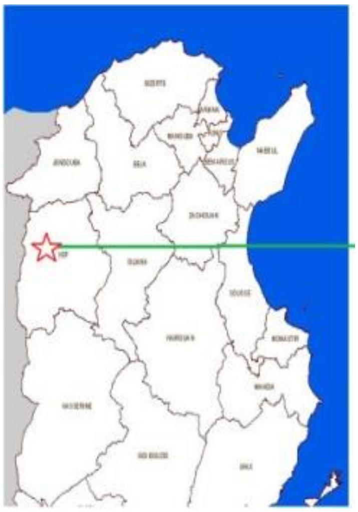

Fig. 1. Location of case 1A, in Tunisia

Importance of cereals in the local agriculture:

Economically, the governorate of Kef is an excellent agricultural region. It contributes in the national production of 10% of cereals, 3.4% of milk and about 7% of meats. The uncultivated lands cover about 10.600 ha, and the total agricultural area of the governorate covers 497.500 ha (97.9%). This area includes forests, rangelands and arable land which constitute the useful agricultural area. 75% of the farms sizes in kef governorate are less than 20 ha, among which 23.3% are farms between 5 and 10 ha. The remaining farms (25%) are greater than 20 ha. Rainfed cereals occupy the first place of the cultivated crops in those farms (about 200.000 ha).

Current Cereal-based cropping system:

The combination of cereal cultivation (durum wheat, bread wheat, barley, triticum), and livestock are the most frequent systems in the semi-arid area of Kef. Crop rotation can include legumes or forages. Rape seeds are also cultivated in some areas. In others regions of the governorate the expansion of irrigated areas allowed introduction of olives and fruits trees in the cropping system.

Environmental, socio-economic, and technical constrains:

Different constrains can be reported facing farmers in the region mainly:

- The instability of the climate conditions: Insufficient and irregular rainfall during the crop cycle (Drought, erosion and hail risk).
- Lack of inputs and their price are expensive
- Small farmers generally have problem of mechanization during sowing and harvesting.
- High debt ratio of farmers.
- Lack of financial support for small farmers

Plots and trial description:

Trials will be conducted in Kef INRAT experimental station as recommended in the project. Trials of WP2 will focus on Optimization of Camelina choice variety, sowing and harvesting strategies. Parameters as Cycle length, seed production, and seed qualitative traits will be recorded in addition to the optimization of agronomic protocol for Kef region.

2.1.2 Case 2A:

Region: Marchouch (Khémisset Province of the Rabat-Salé-Kénitra Region) and Sidi El Aidi (Settat Province of the Chaouia-Ouardigha Region), **Morocco.**

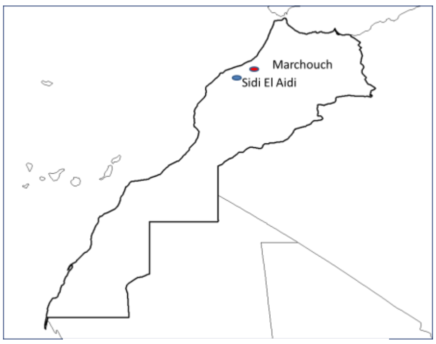

Fig. 2. Location of case 2A, in Morocco

Climate, geography, and demographics:

Most of Morocco north of the Western Sahara, particularly along the coasts, experiences a typical Mediterranean climate, with mild wet winters and hot dry summers. The rainy season generally extends from October to April. Morocco is on the southern margins of the mid-latitude tract of frontal storm systems that regularly traverse the North Atlantic. As a result, rainfall levels are relatively low and gradually decrease from north to south. In the broad coastal lowlands, average annual precipitation diminishes progressively from about 800 mm on the northern Gharb plain to less than 200 mm in the Sous valley. Further south, beyond the Anti-Atlas, semiarid conditions quickly fade into desert (Oxford Business Group 2020).

At the north-west corner of Africa, just 15 km from Europe across the Strait of Gibraltar, Morocco has a strategically important location and for centuries has been a blend of cultures. Morocco's territory covers 710,850 km^2, located Nort-West of Africa. Its coastline on the Atlantic Ocean and the Mediterranean totals 3500 km. Morocco has land borders of just over 2000 km with Algeria, the Spanish enclaves of Ceuta and Melilla (plus the tiny rock of Peñón de Vélez de la Gomera) and Mauretania.

Moroccan population has more than tripled since 1956, rising from 10.5m in 1956 to hit 33.8m, according to a 2014 census. Morocco is a young country – 26% of the population is under the age of 14, and 17.2% are between 15 and 24 years old. The majority live in the more fertile, lower-lying north and along the Atlantic coast, where most major cities are found. The population is growing at around 1.3% a year, according to the World Bank, and like other developing countries, Morocco has seen rapid urbanisation over recent decades, with its urban population rising from 29% in 1956 to current levels of 60%. One major challenge for the government is bringing down youth unemployment, which is around 20% (Oxford Business Group 2020).

Importance of cereals in the local agriculture

The arable land in Morocco is estimated to be 8.4 million hectares, which represents approximately 18.8% of the total area of the country, out of which more than 80% is dedicated to rainfed agriculture. About 43% of arable land is devoted to cereals and only 3% to legumes. In a period of 50 years, cereal area varied from 4. 5 to 5.3Mha contributing to a 3.2 fold increase in cereal production (from 2.5 Mi tons in 1961–1965 to more than 8.0 Mi tons in 2008–2010). Even though area under various cereal crops varied year to year, nearly 40-50% of area is cultivated with bread wheat and remaining area is occupied by durum wheat and barley. For instance, the area planted during 2016-2017 cropping season was around 3.2 Mha (47% bread wheat, 18% durum wheat, and 35% for barley; USDA-FAS 2016). However, production varies from year to year based on rainfall and its distribution during cropping season. Occurrence of recurrent drought season in Morocco is very common, resulting in a reduction in cereal yield and production. For example, cereal production in the 2018-2019 has reached 5.2 Mi tons, down by 49 % compared to last year, due to severe drought. In addition, the wheat yields during normal seasons are still low and stagnant even after adoption of fertilizers and appropriate crop cultivars (Mrabet et al. 2012). As a result, Morocco is not self-sufficient in this cereal production and imports these cereals for domestic consumption.

Current Cereal-based cropping system

In Morocco, several wheat-based systems namely, (1) continuous wheat, (2) wheat-fallow, (3) wheat-lentil, (4) wheat-corn-fallow, and (5) wheat-forage-fallow are in vogue (Mrabet et al. 2012). The first two are predominant. Use of legumes in the crop rotation is not predominantly followed because of their susceptibility to biotic and abiotic stresses, weed menace and consequential labour-intensive control, and other labour-intensive agronomical practices. Thus, there is a need for an alternative crop for deployment in cereal-based cropping system for crop diversification and improve soil health.

Environmental, socio-economic, and technical constrains

According to the 2012 national GHG inventory, agriculture alone (without food processing, including land use change and excluding energy) is in fact the second highest emitting sector in Morocco and responsible for 21.3% of total emissions. The agricultural sources of emission include livestock-related activities such as manure left on fields/pastures, synthetic fertilizers, burning of crop residues etc. (FAO 2016a). Regarding the socio-economic problems faced by Moroccan farmers, one of the biggest concerns is the rising input prices, particularly for fuel, chemicals, fertilizers, and machinery, and constant, or even declining, prices for the commodities they produce and decreased net profitability.

From a technical perspective, a significant number of studies in Morocco within the last 3 decades, dealt with the effects of NT (no-tillage) systems on crop yields for different wheat rotations under rainfed conditions. They showed benefits of NT over CT (conventional-tillage) systems (Mrabet et al. 2012), such as the ***agronomic benefits,*** where these long-term trials have shown the following: (1) no-till system produces higher yields than conventional tillage systems; (2) crop rotation increases and stabilizes wheat yield more than continuous cropping; (3) no-till system plus crop rotation result in better energy conversion and balance than conventional tillage and continuous cropping; (4) no-till system combined with crop rotation is more lucrative and results in less risk as compared to conventional tillage and continuous cropping; (Mrabet, 2008).

The agronomic characteristics are strictly tied to ***environmental benefits*** of NT entail soil erosion reduction, improved soil water conservation, soil fertility and health and CO2 emission mitigation (reduced fuel use, etc.), enhanced carbon sequestration in soil, and reduced synthetic fertilizer use, combined with higher net returns by NT systems (Mrabet et al. 2012).

From another perspective, ***social benefits*** derive from NT, that permits greater stability in yields (Mrabet,2011). No-tillage has enabled to reduce cost of wheat production and increase yields over CT by facilitating timeliness in planting, i.e. 1–2 weeks earlier planting (Bouzza,1990). Early planting is also associated with reduced seeding rates and better management of crops in terms of weed control and fertilizer use. These efficiencies normally lead to an increase in farmer's incomes. NT-systems allow poverty reduction due to lower costs and higher incomes, reducing drudgery, giving more time for other economic and social needs (more spare time) (Mrabet et al. 2012).

Despite the advantages of NT and its introduction in Morocco nearly 3 decades ago, adoption of NT by the farmers is very slow. (1) A key pillar of NT -- ensuring permanent soil cover especially by crop residues -- is indeed difficult to do locally due to widespread non-conservative agronomic practices related to the management of crop residues. The crop residues are in fact removed from the fields (sold out) and/or consumed on site through grazing. (2) Another practice representing a key feature of NT -- diversifying and rotating crop varieties -- has been gradually abandoned over the past 30 years (Bourarach, 1998), because, most of food legume crops are unsuitable for deployment in rotations: these food legume crops such as lentils, faba bean, chickpea etc. are susceptible to biotic and biotic stresses, weeds, and labour intensive operation in food legume fields such as weeding and harvesting operations resulted lower net income from growing the food legume crops. (3) most of farmers are small farmers (70%; less than 5 ha) and not able to afford expensive equipment for planting and harvesting (Mrabet et al. 2012; FAO 2016). In this sense, Camelina, being a short cycle crop with high weed suppressing ability makes it suitable for deployment in crop rotation in wheat-based conservation agriculture system. In addition, it has food and feed value, and stubble could be not suitable for grazing by animals.

Plots and trial description:

The locally adapted strategies for Camelina sowing were developed in consultation with Local Multi-Stakeholder Platforms (LMSP). The details of the trials are as follows:

- Tillage systems: Comparison of minimum tillage and conventional tillage systems
- Plot size: 12 m^2 for each replication
- Camelina variety selected: Alba
- Planting dates: 2 namely early (planted during optimal date for wheat planting) and late (usually one month after usual planting date of wheat)
- Seeding rate: High (800 seeds/m^2, broadcating) and low (600 seeds/m^2 planted in row with row spacing of 18 cm)
- Fertilizer application: N only as top dressing at rosette stage at 50-60 kg/ha as urea
- Number of replications: 4

2.1.3 Case 3A:

Region: Sétif (high plain area) / Setif, **Algeria.**

Climate, geography, and demographics:

- Area: 6 504 km^2
- Dry Mediterranean climate (hot, dry summer / cool, wet winter)
- 400 mm yearly rainfall, frost, and snow in January
- Average monthly temperatures exceed 40 ° C in July and August while in winter, monthly average temperatures can reach 4 Cº
- 900-2000 masl
- Rangelands are annual fallow (stubble), permanent grasslands in wet areas (restricted), collective semi-mountainous or forest pastures 1,496 million (2008)
- Farm size typically < 10 ha
- 80% of farms private / 20% public (public owns “better” lands)

Fig. 3. Location of case 3A, A in Algeria

The Sétif area is characterized from the geomorphological point of view by three zones: the North Zone is a mountainous zone which extends from East to West on a hundred kilometers and which includes in the East the Babors mounts (2000 m) and in the extreme west the Bibans mounts (1600 m). The high plains area is a huge, relatively flat expanse with an altitude of between 900 and 1000 m; and the southern zone has altitude that varies between 1000 and 1500 m.

Importance of cereals in the local agriculture:

The semi-arid area of Setif is usually presented as land dominated by rainfed cereals, wheat and barley, and livestock farming. The cropping system is based on a cereal / fallow rotation. Fallow land currently occupies

40% of the useful agricultural area (Abbas and Abdelguerfi, 2005). All the farms practice the cultivation of cereals and very reduced breeding. A clear trend towards diversification facilitated by access to irrigation is present. In particular, market gardening and potato cultivation is observed regardless of the size of the farm (Boudiar, 2013).

Current cereal-cropping system

In semi-arid cereal zones, production systems are often unstructured and subject to constraining climatic hazards. Fallow is then the tool which makes it possible to promote either cereals, in case of rain, by its early plowing, or livestock breeding, in the event of drought, by grazing (Abbas et al., 2001). The combination of cereal cultivation, fallow and livestock can best manage climate risk by favoring one set of products at the expense of another. The mixed farming can then be perceived a double-edged sword: positive for the financing of campaigns in general but can induce a significant financial burden in some scenarios (Benniou and Aubry, 2009).

Environmental, socio-economic, and technical constrains

Different constrains from these dimensions in the Algerian context, were Model A will be implemented, are mentioned ahead: recurrent drought and erratic rainfall in the designated areas, low organic matter in the soil, plant diseases, lack of extension of small mall scale farms (UAA), no respect of technical itinerary, expensive inputs, land tenure, no organization of cereal growers in cooperatives.

Plots and trial description:

The trials, conducted on cereal breeding, consist the improvement and selection of new varieties of durum wheat, bread wheat and barley. The objectives researched are adapted to local environment, higher yield, and its stability.

2.1.4 Case 4A:

Region: Castilla La Mancha, **Spain**

Climate, geography, and demographics:

The climate of Castilla-La Mancha can be described as continental Mediterranean, characterized by cold winters and hot summers with strong temperature fluctuations and a more abundant irregular rain regime in autumn and spring. Temperatures commonly drop below 0ºC in most of the region during winter. The average temperature in January is below 6º C, with numerous frosts occurring on cloudless nights; frosts are also frequent in early spring and late autumn. In summer they frequently exceed 30º C, reaching sporadically more than 35º C.

Fig. 4. Location of case 4A, A in Spain

Castilla-La Mancha is included within the so-called "dry Spain" - rainfall is low and typically between 400 and 600 litres per square meter per year. The aridity indices are very high, especially in La Mancha and the southeast. Castilla-La Mancha is located in the heart of the Iberian Peninsula, being the third largest Spanish region, with a surface area of 79,409 km^2, which represents 15.7% of the Spanish territory. The plain dominates the territory, since almost 80% of the regional surface does not exceed 1,000 meters above sea level. Over 2.1million people live in Castilla La Mancha, representing approximately 5% of Spain's population. The population under 25 years of age represents 26.9% of the total in CLM and those over 65 years of age close to 17.6%.

Importance of cereals in the local agriculture:

According to the latest available data, corresponding to the 2016 agriculture census, there are 272,335 cereal farms in Spain. The average size is 24.2 hectares and most of the farms and surface area is concentrated in Castilla y León, and Castilla La Mancha, which concentrates 19.39% of the total farms and 8.84% of the total area. An average of 6 million hectares of cereals are cultivated across the country, being the sector with the largest territorial base. The distribution of the surface is very wide throughout the Spanish territory. The main cereal growing regions are Castilla y León, Castilla la Mancha, Aragon and Andalusia. Castilla la Mancha is the second largest production region (following Castilla La Mancha), with 22% of the area and 18% of the production. The main cereal production is barley and wheat and it is the main producing region of oats and triticale (Spanish Ministry of Agriculture, 2019).

Current Cereal-based cropping system:

Most of Castilla La Mancha is a semi-arid region, with low precipitation, high risk of desertification (Martínez-Valderrama et al., 2016) and high fallow land periods. These are impoverished areas which are typically characterized by monoculture production of barley in rotation with fallow land. These areas generally cannot introduce typical European oilseeds in their crop rotation as they are not viable: it rains too late in autumn for rapeseed and not enough during spring for sunflower. These farmers require an alternative oilseed crop to introduce in their rotation scheme in order to allow them to reduce the fallow land periods due to the benefits this rotation scheme provides compared to monoculture cropping, including: improving soil structure, nutrient cycling, fertilizer efficiency, herbicides efficiency for weeds control, increasing yields in the long-term and reducing soil degradation.

Environmental, socio-economic, and technical constrains:

At an environmental level, rainfed regions in Castilla La Mancha face various problems, including recurrent droughts and low levels of organic matter in the soil, with a high risk of desertification. At a socioeconomic level, the low population density is one of the main problems that the region faces, and one that takes on special importance on the primary sector, which is the most affected.

Plots and trial description:

The camelina trials are focused on the optimization of variety choice, which will be selected based on cycle length, resource use efficiency (water and nutrients), seed production, and seed qualitative traits. Additionally, both sowing and harvesting strategies will be implemented, in order to optimize a camelina agronomic protocol for the region.

2.2 MODEL B

The model is to be tested in Italy, Greece and Southern France, where Camelina is introduced as a double-cropping cultivation in autumn, to precede typical Mediterranean summer crops, e.g., sunflower, soybean, sorghum etc, in milder climate with adequate precipitation during summer.

2.2.1 Case 1B:

Region: Bologna, Emilia-Romagna, **Italy**

(The 4CE-MED trials have been established at the experimental farm of the University of Bologna, located at Cadriano, 10 km far from Bologna, in Emilia Romagna region in northern Italy (44°33´ N, 11°23´ E).

Climate, geography, and demographics:

The climatic conditions in Cadriano are the one typical of the North Mediterranean climate characterized by mild and wet winters and warm dry summers, with a mean annual temperature of 13.4°C and cumulative annual precipitation of 613 mm (ARPA, 2019). In general, the region has these characteristics:

Fig. 5. Location of case 1B, in Italy

- Humid temperate climate
- Quite cold and damp winters are, while summers are hot and muggy.
- The monthly average temperature ranges from 3 °C (37.5 °F) in January to 24.5 °C (76 °F) in July.
- Precipitation is moderate, since it amounts to 670 millimeters (26.4 inches) per year
- Altitude 32m masl (area of the pilot in Cadriano, Bologna)
- Area: 3.703 km² (Province of Bologna)
- The site is characterized by a silty clay loam soil.
- The province is in the south-eastern part of the Po Valley, 70 km (45 mi) away from the Adriatic Sea.
- 8.740 farms or agricultural companies are present in the province of Bologna

Importance of cereals in the local agriculture:

The importance of cereals in the local agricultural system is evident in the region where this study is located. Emilia Romagna in one of the most important regions in Italy for cereals production. Reporting ISTAT data from the period 2014-2018, cereal production in the region is attested on 2.1 million tons/year (ISTAT, 2019). Cultivated by over 31 000 farms, that represent more than a half of the total farms of the regional area, with a total area of 311 000 ha divided as reported: 127 000 ha cultivated with bread wheat, 62 000 as durum wheat and 69 000 with maize.

Current cereal-cropping system:

Currently, the most widely winter cereals cultivated in Emilia Romagna are common wheat and durum wheat, otherwise as spring cereals sorghum and maize are the more widespread. Mainly two different areas can be individuated in ER: the plain area and the hilly area. The latter is characterized by barley and bread wheat cultivation in winter and sunflower in spring. While in the plain area is characterized by the cultivation of common and durum wheat in winter, and maize, soybean, and sorghum in spring.

Environmental, socio-economic, and technical constrains

From an **environmental perspective**, Cadriano, the Province of Bologna and the region of Emilia-Romagna are being involved in climate change phenomena, as demonstrated by the 2019 on climate released by the environmental control agency of the Region, ARPAE ER. The acclaimed increase in temperatures, with increasingly frequent and anticipated heat waves, causes a worsening of the hydrological balance in the spring-summer period with a considerable increase in the water requirements of the crops and an advance of the phenological season. This may cause disequilibrium in the nitrate level of soils. From a nitrate perspective, leakages in ground water can also be cause by intensive cattle breeding, common in the region and the province of Bologna (ARPAE, 2019). From a **social perspective,** agriculture presents issues related to rural development, land abandon, immigrant’s worker conditions. Several regional policies are addressing these issues, promoting traditional agricultural activities to multifunctional ones, tackling social issues (AgriRegioniEuropa, 2018).

Trial description

The 4CE-Med trials within WP2 have been established at the experimental farm at Cadriano. The individual plot size is about 100 m^2. The soil was prepared under minimum tillage system (disking + superficial harrowing). The sowing was performed with the cultivar Alba (provided by Camelina Company España), sown with a with a seed drill (DAMAX 17), with a rate of 600 seeds/m^2 and an interrow spacing of 17cm on the 28th of October 2020. Emergence (10-20-30 DAS), soil coverage, phenology and heights will be surveyed during the cycle. 2 different harvesting strategies will be applied: harvesting at 12% R.U of the seeds and the second one cutting and swathing at 35% R.H of the seeds. After harvesting, the succeeding crop will be established (soybean) and the productive parameters will be surveyed. For comparison side by side plots with winter barley have been established to make direct comparison between the 2 crops.

2.2.2 Case 2B:

Region: Occitany area – NUTS 2, Lauragais farming region near Toulouse, and located across 3 departments (NUTS 3): Haute-Garonne, Aude, Tarn, **France.**

Climate, geography, and demographics:

Both oceanic and Mediterranean influences are observed in Lauragais with a mild winter (Table 1), warm and dry summer.

November and May are the rainiest months with erosion issues in April and May.

Fig. 6. Location of case 2B, in France

Table 1. Climatic data for Southwestern France from 2004 to 2019 – En Crambade

Month	Temperature min (°C)	Temperature max (°C)	Average Temperature (°C)	Rainfall (mm)	Potential evapotranspiration (mm)
January	2.2	9.5	5.9	70.6	11.7
February	1.6	10.8	6.2	44.4	25.7
March	3.9	14.6	9.2	56.4	59.6
April	6.8	18.1	12.4	70.5	89.4
May	10.0	21.1	15.6	74.8	118.0
June	13.5	26.0	19.7	49.1	141.8
July	15.0	28.7	21.8	45.5	154.6
August	14.7	28.4	21.6	40.6	137.3
September	12.3	25.4	18.8	41.3	95.5
October	10.2	20.5	15.4	50.8	57.7
November	5.9	13.7	9.8	65.4	20.2
December	2.8	10.4	6.6	45.8	9.6
Year	**8.3**	**19.0**	**13.6**	**655.0**	**921.0**

(Source France AgriMer)

Landform is composed of large hills with chalky clays soils, deeper and with higher loamy content at the bottom and shallow soils with higher chalk content at top. Slopes could impact soil tillage and erosions issues. The area is a homogenous unit of cropping systems, soils, and climate conditions, delimited by different counties (group of municipalities).

Importance of cereals in the local agriculture

Lauragais is a large arable crops area mainly with cereals, oil and protein crops. Crop rotation is based on winter cereals every two years. Winter cereals acreage (Table 2) is over 56 000 ha for near to 140 000 ha of total cereal, oil and protein crops.

Table 2. Surface area of cash crops into Lauragais area (Southwestern France) – SCOP, total Surface area Oil, Protein and Cereal crops

	SCOP	Bread Wheat	Durum Wheat	Barley	Rapeseed	Sunflower
Surface area (ha)	138851.35	25010.45	31380.61	7787.42	3180.6	32093.75
Surface area (% SCOP)	100	18	23	6	2	23

(Source France AgriMer)

The agronomic potential of Lauragais area is impacted by various climatic parameters or biologic threats. Final yield observed is not so high but highly variable across years and localisation in the region. For instance, average yield for bread wheat between 2014 and 2019 was 5.01 t/ha in the Aude Department, 5.40 t/ha in the Haute-Garone Department, and 5.29 t/ha in the Tarn Department. Rapeseed average yield ranges from 2.7 to 2.9 t/ha in the same departments.

Current cereal-cropping system:

Lauragais is a historical production area for durum wheat. Bread wheat is produced in the western part of Lauragais and all the western chalky clay hills around, as the main crop with quality objectives (high protein content). Sunflowers complete this main short crop rotation: sunflower-wheat. Cropping systems including winter cereals are mainly managed in rainfall conditions. Irrigation is sometimes available for seed production. Winter cereals can be irrigated to improve nitrogen efficiency during stem elongation and to prevent from draught while grain is filling. Winter or spring peas, so as sorghum are managed for a long time in this area but on little surface area. Due to technical problems, diversification starts with an increasing surface area of sorghum, soybean and chickpea. Oilseed rape is also managed with several problems of draught at emergence. Soils are largely ploughed every two years after cereals.

Environmental, socio-economic, and technical constrains

This short crop rotation is facing **technical and environmental restrictions**. Soil erosion is increasing in May with heavy rainfall on ploughed field for 8 months before. Weed pressure in winter cereal fields is another increasing issue with ryegrass, resistant to many herbicides. Such cropping systems are facing **economic** bottlenecks with low profitability due to high inputs, yield variability, low market prices and global warming. New opportunities such as renewable energy from biomass are studied in these intermediate zones. On farm biogas plant development is an opportunity to diversify cropping systems especially with double cropping systems which decrease food/non-food competition. In consequence, camelina is an opportunity for these systems to grow a summer energy double crop or camelina for grain after a winter immature cereal.

Plots and trial description:

The objective of the experiments will be to test varieties and their ability to compete weeds as ryegrass in such cropping systems. For camelina grown on winter, harvest date is a crucial parameter to measure capacity to grow a following summer crop. Harvest chain will be tested regarding this issue. Climatic variability will be analysed threw these observations. Camelina sown on late spring will also be studied after an energy winter catch crop. Three locations undertake model B trials in this Southern France case. The Castelnaudary site will trial camelina varieties through 8 modalities (6+Alba 600pl/m² + Alba 800 pl/m²) in plots with 3 replications; soil tillage will be superficial with following crop.

A second site, Baziège will trial seed density and harvest techniques with two modalities of the variety Alba. The method will be of large-sowed strips completely harvested in two dates, and superficial soil tillage. Replications are to be confirmed; weed control in both modalities and soybean or sorghum as following crops will be considered.

Finally, Boigneville is the third site to trial seed density and weed control using Alba variety. There will be three modalities and the large strips completely harvested method will be applied, tillage will be superficial and weed control in both conditions (with Barralis method), and biomass sampling will be included.

2.3 MODEL C

This model is set in Northern France, and Camelina is introduced as a double-cropping in late spring/early summer in colder areas to follow winter pulses (e.g. pea) or cereals harvested as fodder.

2.3.1 Case 1C:

Fig. 7. Location of case 1C, in France

Region: Barrois, north-eastern France across Burgundy and Champagne-Ardenne area (NUTS 2) from Nancy to Dijon cities, located across 6 departments (NUTS 3), **France.**

Climate, geography, and demographics:

Barrois is characterised by a continental climate (Table 4). Winters could be cold and dryer than the rest of the year. Autumn and May are the rainiest periods. Despite a regular rain, spring and summer could be dry. Soils are not deep and mainly composed of clay with significant chalk content which impacts tillage and nitrogen management. This is a large farming area representative for intermediate zone on chalky clay to chalk highlands.

Table 3. Climatic data for North-eastern France from 2004 to 2019 – Dijon

Month	Temperature min (°C)	Temperature max (°C)	Average Temperature (°C)	Rainfall (mm)	Potential evapotranspiration (mm)
January	-0.1	5.6	2.7	59.5	16.9
February	-0.3	7.4	3.5	41.5	27.0
March	2.4	12.3	7.3	52.6	58.4
April	5.7	16.7	11.2	61.1	84.9
May	9.1	20.0	14.5	77.5	107.3
June	13.1	24.7	18.9	68.3	141.4
July	15.0	27.0	21.0	68.5	162.7
August	14.2	25.6	19.9	70.9	131.2
September	11.2	22.2	16.7	45.0	91.0
October	7.8	16.8	12.3	70.0	45.5
November	3.7	10.0	6.9	72.7	21.0
December	0.6	6.2	3.4	63.4	15.9
Year	**6.9**	**16.3**	**11.6**	**750.9**	**903.2**

(Source France AgriMer)

Importance of cereals in the local agriculture

Bread wheat, barley and rapeseed surface area reaches 80% of the whole SCOP, as described in table 4. Average yield of soft wheat is lower than the other northern areas (i.e. Champagne area). Soft wheat yield for the last 15 years is around 6.5t/ha with higher potentialities near chalk area of Champagne (Aube department). The bread wheat average yield from 2004 to 2019 for different departments are mentioned ahead: Aube registered an average yield 7.8 t/ha, Cote-D'Or 6.5 t/ha, Haute-Marne 6.5 t/ha, Meurthe-et-Moselle 6.5 t/ha, Meuse 7t/ha, Haute-Saone 6.7t/ha, Vosges 6.2t/ha and Yonne 6.5t/ha.

Rapeseed yield is a bit higher than the reported in the Southern region of France, from 3.1 to 3.4 t/ha. These potentials express pedoclimatic conditions with shallow soils and fluctuating conditions across growing cycles.

Table 4. Surface area of cash crops into Plateaux de Bourgogne area (Northeastern France) – SCOP : total Surface area Oil, Protein and Cereal crops

	SCOP	Bread Wheat	Durum Wheat	Barley	Rapeseed	Sunflower
Surface area (ha)	490152.41	178598.64	110.51	152581.54	84961.11	11753.8
Surface area (% SCOP)	100	36	0	31	17	2

Current cereal-cropping system:

Main cropping system is composed of winter or spring crops with a short crop rotation: rapeseed, bread wheat and spring or winter barley. Irrigation is not largely deployed in the area.

Environmental, socioeconomic and technical constrains

Mentioned cropping systems face many **technical and environmental** problems due to global warming. The short crop rotation based on cereals and winter cycles encourages weed development. High densities of ryegrass or vulpine are observed into the fields and chemical options are decreasing.

In the case of rapeseed flea beetle (*Psylliodes chrysocephala*) causes important damages in autumn added to emergence problems with draught in late August and beginning of September. This crop needs relevant crop protection all over the growing season. Expenses get higher with fluctuating yield and global profitability of local farms is heavily impacted nowadays. To deal with it, new opportunities such as renewable energy from biomass are studied in these intermediate zones. On farm biogas plant development is an opportunity to diversify cropping systems especially with double cropping systems which decrease food/non-food competition. Camelina is an opportunity for these systems to grow a summer energy double crop or camelina for grain after a winter immature cereal.

Plots and trial description:

Both camelina with autumn sowing and spring sowing are interesting for the area. Spring sowing represents a proper scenario for new multifunctional cropping systems including food and energy crops. Camelina cycle will be characterised for sowing at mid-May. For autumn sowing, harvest date and methodologies will be the main topic to allow a good development of the following crop. Two sites will entail this model. The first defined site is Montgenost; which will trial camelina varieties in plots with superficial soil tillage. A second location, also in Montegnost, will trial with large strip method and direct seeding with superficial tillage will be conducted. Finally, a third site, yet to be defined will also test one camelina variety in large strips, and with direct/superficial tillage.

3 General methodology

3.1 Sustainability assessment

Global food production heavily contributes to natural resources overexploitation, accounting for more than 70% of freshwater withdrawal and for about 30% of all greenhouse gases of anthropogenic origin (Angelo et al., 2019; Garnett, 2011; Whitmee et al., 2015). The current food system generates unbalanced effects on food security and health, with more than 820 million people struggling with hunger and 680 million obese individuals (FAO et al. 2018a). In the social domain, agricultural workers account for two thirds of the world extreme poverty, in addition to be the most affected by natural catastrophes. The hidden costs of the food system's strain on health and the environment, as well as other economic costs, such as rural welfare or food loss and waste (FLW), amount to $12 trillion (The food and land use coalition, 2019).

The intensification that has been occurring in the food sector during the past decades is damaging the state of the planet resources and compromising its productiveness, while insufficiently providing food and nutrition for all (FAO, 2018a). In a 2050 scenario, an intensification of 119% in edible crops production would be needed to feed the expected increase of the world population (Berners-Lee et al., 2018). This substantial growth will be inevitably associated with a rise in the exploitation of natural resources, potentially threatening the ability to produce food and accordingly challenging food security (Prosekov and Ivanova, 2018).

On the other hand, agriculture represents a key sector to actively address sustainability. From the climate perspective, it can contribute to climate change mitigation by reducing emissions intensity (improving production efficiency) and avoiding additional loss of the carbon stored in forests and soil (FAO, 2016b). It is demonstrated that agricultural productivity also benefits from the development of human and social capital, such as facilitating the provision of training for workers to learn new professional skills, accompanied by an introduction to available technologies to improve production efficiency. The expected farmers' increase in market condition readiness would provide a better socio-economic field of play (OECD-FAO, 2019).

Targeting sustainable food systems requires a holistic approach aiming at successfully providing food security and nutrition, benefiting the society, and creating a positive or neutral impact to nature (FAO, 2018b).

3.1.1 How sustainability can be measured

Since sustainability represents a major challenge for current food and production systems, the research for appropriate tools and approaches for its measurement involved several scientific disciplines.

Cost-Benefit Analysis (CBA) is a major instrument applied to evaluate sustainability. CBA combines prices flow analysis, environmental consequences (by including externalities), and the social perspective of different projects or policies. It mostly adopts money or welfare as a unit of reference (Hoogmartens et al., 2014). International organizations have also elaborated sustainability tools, such as The Food Agricultural Organization, FAO (2014), with the design of specific guidelines for assessing the impact of food and agriculture operations on the environment and people. Similarly, the Global Reporting Initiative wants to support businesses and governments to understand and communicate their impact on sustainability by providing a set of specific standards (GRI, 2019). The interest of investors on this topic has promoted the creation of dedicated indexes such as The Dow Jones Sustainability Index (DJSI), widely recognized in the stock sphere and considered as an acceptable proxy of sustainability (Chams and García-Blandón, 2019). Also, certification standards, such as Fairtrade or Rain Forest Alliance, propose product information about ethics, environmental or social features of food products (Vecchio and Annunziata, 2015).

Within this framework, the methodological approaches most widely adopted are those under the life cycle thinking (LCT) approach including Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) and the integration of the three into the Life Cycle Sustainability Assessment (LCSA). These techniques allow individuals and businesses to assess the impact of their decisions and production methods along with different aspects of a system or a value chain (UNEP, 2011).

3.2 Life cycle thinking (LCT) approach

Current food systems need to be urgently redesigned as they are unable to feed a growing global population ensuring social justice and environmental sustainability contemporaneously. The building blocks for a transition to more sustainable food systems should address its inefficiencies, drawing attention to the wide range of environmental, economic, and social impacts derived from these systems. The evaluation of sustainability represents a challenge as it involves the understanding of different disciplines, actors, and concerns along the food supply chain. Among the different methodologies of evaluation, the Life Cycle Thinking (LCT) approach emerges as a complex and complete integrated assessment method unveiling the environmental, economic, and social impacts occurred in each segment of the food supply chain while providing improving scenarios.

3.2.1 Life cycle assessment

LCA is a methodology that considers and analyses a product over its entire life cycle to quantify its environmental impact. It is standardized by the ISO 14040:2016 which defines the principles and framework where the method should be performed (ISO, 2006, 2002).

After performing a literature review using Scopus engine search, we observed very limited LCA performed in the Camelina crop in Mediterranean regions. Most of the information found is referred to the application of Camelina as biofuel, while some articles even highlighted that camelina is not used as food. Certain outputs compared different rotation crops which might be useful to the scope of this work. In order to improve comparability of studies, this research will try to use same functional units as other research as well as the most relevant impact categories. Main outcomes from relevant publications, due to the topic, geographical location and number of citations have been included.

General search summary of the search:

search 1			search 2	
"LCA" AND	camelina	16	AND "Mediterranean"	1
	oilseed	93		3
	wheat	451		8
	barley	79		1
	corn	378		1
	sorghum	57		3
	sunflower	63		2
	cotton	111		1

According to the main findings, we can conclude that:

- There are not many LCA performed for Camelina in the Mediterranean context, but some studies can be utilized for comparative purposes.
- There are several LCA studies focused on current crops such as wheat, corn and sunflower which could support in the development of the baseline scenario.
- Most of the studies are focused on crops for energy purposes.

Below, a summary of the literature review that was performed:

Title and authors	Life cycle assessment of camelina and crambe production for biorefinery and energy purposes; Michał Krzyżaniak and Mariusz Jerzy Stolarski
Geographic area	North-eastern Poland
Aim of the Research	The study compared the environmental impact of crambe and camelina cultivation systems with reduced tillage (RT) and traditional tillage (T) land management practices and different paths of possible biomass uses.
LCT applied	LCA
Assessed crop(s)	Camelina and Crambe
Functional Unit	a functional unit of 1 Mg of oil and 1 Mg of seeds was assumed (oilcake may be used for other purposes such as animal feed, briquettes and pellets)
System boundaries	An attributional approach was used for the analysis and the "from cradle to biorefinery gate" system boundaries were adopted.
Impact categories	LCA was determined by the IPCC 2007 and ReCiPe Endpoint methods. Moreover, based on the ReCiPe Midpoint and Endpoint (H) method v. 1.04, the effect of camelina and crambe production was determined in the following three areas of protection: human health, ecosystems and resources, as well as in the midpoint categories: climate change human health, climate change ecosystems, ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation, ionising radiation, terrestrial acidification, freshwater eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation, natural land transformation, metal depletion and fossil depletion. The midpoint categories also characterise environmental effects (typical of agriculture) of the use of fuels, fertilisers and plant protection

	products, e.g. acidification, eutrophication, toxicity, agricultural land occupation, natural land transformation and fossil depletion
Software utilized	SimaPro
Main limits	it is necessary to further develop the technologies of using oils from camelina and crambe and study the cultivation of varieties which could compete with traditional oil crops.
Other information	The emission of CO2 eq. from the cultivation of both crops per 1 ha was similar. When converted per 1 tonne of dry seeds was more varied (1,152–1,528 kg CO2 eq.). The highest normalised score for all crops was determined in fossil depletion. Reduced tillage results in lower impact compared with traditional tillage.

Title and authors	Biodiesel production from unconventional oilseed crops (*Linum usitatissimum* L. and *Camelina sativa* L.) in Mediterranean conditions: Environmental sustainability assessment; Jacopo Bacenetti; Andrea Restuccia; Gianpaolo Schillaci; Sabina Failla
Geographic area	Mediterranean
Aim of the Research	The environmental impact of *Linum usitatissimum* and *Camelina sativa* oilseed crops for biodiesel production was assessed by Life Cycle Assessment approach considering a cradle-to-gate perspective. The study included three steps: cultivation, oil seed transportation from farm to pressing plant and biodiesel production from vegetable oil by transesterification.
LCT applied	LCA
Assessed crop(s)	*Linum usitatissimum* (flax) and *Camelina sativa* (camelina)
Functional Unit	In this study, different functional units were used. One t of harvested flax and camelina was chosen in order to focus on the agricultural step of the production process. For what concerns the biodiesel, two FUs were used: 1 GJ of energy content to compare the environmental impact of biofuel from flax and camelina; and 1 t of biodiesel to compare the environmental impact of biodiesel from flax and camelina with that of rapeseed (the most produced biodiesel in Europe)
System boundaries	1) crop cultivation (cradle-to-farm perspective), 2) seed pressing and 3) biodiesel production from raw vegetable oil.
Impact categories	climate change (CC), ozone depletion (OD), human toxicity, non-cancer effects (HTnoc), human toxicity, cancer effects (HTc), particulate matter (PM), photochemical ozone formation (POF), terrestrial acidification (TA), freshwater eutrophication (FE), terrestrial eutrophication (TE), marine eutrophication (ME), freshwater eco-toxicity (FEx) and mineral, fossil and renewable resource depletion (MFRD).
Software utilized	The SimaPro 8.0.5 software was used
Main limits	Compared to biodiesel from rapeseed, that from flax and camelina shows a higher environmental impact for all of the evaluated impact categories except for HT-noc due to the higher consumption of fertilisers in rapeseed crop management. Nevertheless, it should be considered that the cultivation of flax and camelina assessed in this study takes place in marginal areas where other crops, such as rapeseed, could not be grown.
Other information	The environmental impact of biodiesel from flax and camelina crops was assessed; A cropping system with no-irrigation and low input was considered; Flax shows higher environmental load respect to camelina except for Ozone Depletion; For

	both the crops, seed production is the main responsible of the impact; Compared to biodiesel from rapeseed the ones from flax & camelina show worst results.

Title and authors	Life Cycle Assessment of Flax and Camelina for Biodiesel Production in Sicily (Southern Italy) Jacopo Bacenetti; Andrea Restuccia; Gianpaolo Schillaci; Marco Fiala; Sabina Failla
Geographic area	Italy
Aim of the Research	To assess the environmental performances of *Linum usitatissimum* L. and *Camelina sativa* L. oilseed crops for biodiesel production
LCT applied	LCA
Assessed crop(s)	Flax and camelina
Functional Unit	functional unit was 1 t of biodiesel produced from the camelina and flax
System boundaries	“cradle-to-factory gate”
Impact categories	"Recipe mid-point method (Goedkoop et al., 2008), the following impact categories were evaluated: climate change (CC, kg CO2 eq), ozone depletion (OD, mg CFC-11 eq), terrestrial acidification (TA, kg SO2 eq), freshwater eutrophication (FE, g P eq), marine eutrophication (ME, kg N eq), particulate matter formation (PM, kg PM10 eq), mineral depletion (MD, kg Fe eq), fossil depletion (FD, kg oil eq)."
Other information	Between the two biodiesels, the one produced from flax shows better environmental results. Respect to camelina, flax has higher seed yield and, except for Ozone Depletion (due to higher amount of seed used at sowing), shows lower environmental impacts (ranging from -20% to -30%).

Title and authors	The role of co-products in biorefinery sustainability: energy allocation versus substitution method in rapeseed and carinata biodiesel chains; LorenzoD'Avino; Riccardo Dainelli; Luca Lazzeri; Paolo Spugnoli
Geographic area	Central and Southern Italy
Aim of the Research	The paper analyzes biodiesel chains of rapeseed (*Brassica napus*) and carinata (*Brassica carinata*) cultivated in Central and Southern Italy, assessing the impact on Global Warming Potential by means of the Life Cycle Assessment methodology.
LCT applied	LCA
Assessed crop(s)	Rapeseed and carinata
Functional Unit	the energy unit contained in the biodiesel (one MJ of biodiesel)
System boundaries	the biodiesel chain was considered as formed by four subsystems (or phases): cultivation, oil extraction and refining, esterification, transport and distribution.
Impact categories	Global Warming Potential
Software utilized	So.Fi.A.
Other information	The co-products valorisation should improve the biorefinery sustainability assessment; This occurs in carbon footprint of biodiesel from rapeseed and carinata; Carinata oilcake could be valorised in formulation of biobased amendments; Including biofumigants, the saving vs diesel by energy allocation in Mediterranean Area is 50%; Notably, biodiesel becomes even carbon-negative applying the system expansion method.

Title and authors	LCA Study of Oleaginous Bioenergy Chains in a Mediterranean Environment; Daniele Cocco; Paola A. Deligios; Luigi Ledda; Leonardo Sulas; Adriana Virdis; Gianluca Carboni
Geographic area	South Europe
Aim of the Research	This paper reports outcomes of life cycle assessments (LCAs) of three different oleaginous bioenergy chains (oilseed rape, Ethiopian mustard and cardoon) under Southern Europe conditions.
LCT applied	LCA
Assessed crop(s)	oilseed rape, Ethiopian mustard and cardoon
Functional Unit	1 ha of cultivated field because it is the most straightforward basis for a similar comparative study.
System boundaries	three main phases: cultivation, transportation of agricultural products and their industrial conversion for power generation
Impact categories	energy demand (CED), global warming potential (GWP) and acidification potential (AP),
Software utilized	Simapro software Version 7.3
Other information	the results of the LCA study show a considerable saving of primary energy (from 70 to 86 GJ·ha−1) and greenhouse gas emissions (from 4.1 to 5.2 t CO2·ha−1) in comparison to power generation from fossil fuels, although the acidification potential of these bioenergy chains may be twice that of conventional power generation. In addition, the study highlights that land use changes due to the cultivation of the abovementioned crops reduce soil organic content and therefore worsen and increase greenhouse gas emissions for all three bioenergy chains. The study also demonstrates that the exploitation of crop residues for energy production greatly contributes to managing environmental impact of the three bioenergy chains

Title and authors	Life Cycle Based Evaluation of Environmental and Economic Impacts of Agricultural Productions in the Mediterranean Area; Elena Tamburini; Paola Pedrini; Maria Gabriella Marchetti; Elisa Anna Fano; Giuseppe Castaldelli
Geographic area	North-East of Italy
Aim of the Research	LCA in conjunction with LCC methods were used, with the aim to evaluate the main cost drivers—environmental and economic—of five widely diffused and market-valued agricultural productions (organic tomato and pear, integrated wheat, apple and chicory) and to combine the results in order to understand the long-term externalities impacts of agricultural productions.
LCT applied	LCA and LCC
Assessed crop(s)	organic tomato and pear, integrated wheat, apple, and chicory
Functional Unit	1 kg of fresh harvested crop,
System boundaries	The system boundaries were set from seedlings transplanting for tomato and chicory, seeding for wheat, and orchard plantation for pear and apple, up to the delivery to the local agricultural consortia. Boundaries included also materials and machineries production, fertilizers and pesticides life cycles, packaging management and resources (energy/fuel/water) production, transportation, and consumptions.

Impact categories	Abiotic resource depletion (ARD); Cumulated energy consumption (CED); Water Consumption (WC), and on the following output-related indicators: Global Warming Potential with a time frame of 100 years (GWP100); Eutrophication potential (EP); Acidification potential (AP); Human Toxicity Potential (HTP) and Eco Toxicity Potential (ETP). Impact assessment method CML baseline 2 2002, adjusted with 2007 Intergovernmental Panel on Climate Change (IPCC) indicators for global warming potential (GWP).
Software utilized	SimaPro v.7.3.3
Main limits	Even when the effects of environmental degradation are reasonably well proved, calculating their costs to society remains a difficult task, because of they often occur with a time lag, do not damage specific groups of stakeholders and the identity of the producer is rarely identifiable.

Title and authors	LCA of cropping systems with different external input levels for energetic purposes; Pietro Goglio; Enrico Bonari; Marco Mazzoncini
Geographic area	Italy
Aim of the Research	The research aimed at: (i) to evaluate the environmental impacts of three cropping systems characterized by different external input levels applied to sunflower and maize, both in rotation with wheat, in a Mediterranean region; (ii) to estimate the environmental benefits of the optimization of cropping systems for energy management.
LCT applied	LCA
Assessed crop(s)	Sunflower, maize, wheat
Functional Unit	Two functional units were used: hectare of land and GJ of grain output yield
Impact categories	Output–input ratio, net energy balance, global warming potential (GWP), eutrophication potential (EP) and acidification potential (AP)
Other information	Fertilizer, machine use and irrigation cause most of cultivation environmental impact; Low input systems have greater energetic and environmental efficiency; Sunflower preceding wheat has a positive effect on wheat environmental performance; Comprehensive agricultural LCAs should include land and productivity functional units; Allocation between crop and residues has a significant effect on LCA results.

Title and authors	Contribution of old wheat varieties to climate change mitigation under contrasting managements and rainfed Mediterranean conditions; G. Carranza-Gallego; G.I. Guzmán; R. García-Ruíz; M. González de Molina; E. Aguiler
Geographic area	Spain
Aim of the Research	The goal was to compare the C footprint of old and modern wheat varieties under ORG and CON managements and Mediterranean climate conditions; to identify if the cultivation of high residue producing varieties (OV) could constitute an advantage to climate change mitigation strategies, taking into account their potential benefits for soil carbon sequestration.
LCT applied	LCA
Assessed crop(s)	Wheat and faba bean grains
Functional Unit	1 ha of land and 1 kg of product as functional units.

System boundaries	"Cradle to farm gate" approach, inputs and outputs for the production of one kg of wheat per hectare from the inputs production phase to the emissions derived from N losses from the field.
Impact categories	100-year GWP of nitrous oxide (N2O) and employing a 100-year averaged C sequestration rate.
Software utilized	Database from literature
Other information	C footprint of old vs modern wheat under organic & conventional farming was studied; Old wheat varieties promoted biomass production without decreasing yields; The lowest C footprint was achieved by old wheat varieties under organic farming; SOC balance contributed the most to the reduction of the C footprint; Old wheat rainfed cultivation could be a useful climate change mitigation strategy.

Title and authors	Comparative attributional life cycle assessment of annual and perennial lignocellulosic feedstocks production under Mediterranean climate for biorefinery framework; Amalia Zucaro; Annachiara Forte; Massimo Fagnano; Simone Bastianoni; Riccardo Basosi; Angelo Fierro
Geographic area	Italy
Aim of the Research	This study compares environmental constraints related to fiber sorghum and Giant Reed produced on experimental farms (in the Campania region) using an attributional life cycle assessment (LCA) approach through appropriate modeling of the perennial cultivation.
LCT applied	LCA
Assessed crop(s)	Fiber sorghum and Giant Reed
Functional Unit	1 ha of cropped land and 1 kg of dry biomass harvested, respectively, in the year 2012.
System boundaries	Seed bed preparation to biomass
Impact categories	Climate change (CC; kg CO2 eq; 100-yr time frame); ozone depletion (OD; kg CFC-11 eq); terrestrial acidification (TA; kg SO2 eq); freshwater eutrophication (FE; kg P eq); marine eutrophication (ME; kg N eq); photochemical oxidant formation (POF; kg NMVOC eq); particulate matter formation (PMF; kg PM10 eq); water depletion (WD; m3); and fossil depletion (FD; kg Oil eq). Human and ecotoxicity impact categories were not included in the present study, due to large differences between the impact assessment methods and large uncertainties related to data sets.
Software utilized	SIMAPRO
Main limits	
Other information	LCA highlights linkage between crop yield, management, and environmental sphere; Irrigated (rainfed) annual crops are more damaging than the respective perennials; Except for irrigation, fertilizers had the largest environmental effect in all crops; Environmental burdens increase more proportionally than yield in all energy crops; Results identify no winning crop as environmental burdens depend on site specificity.

Title and authors	A land-based approach for the environmental assessment of Mediterranean annual and perennial energy crops; Stefania Solinas; Paola Deligios; Leonardo Sulas; Gianluca Carboni; Adriana Virdis; Luigi Ledda

Geographic area	Italy
Aim of the Research	This study aimed to assess the environmental burdens related to the agronomic management of different energy crops in a Mediterranean region to support cropping system choices and agricultural land-use planning. Specifically, the objectives were to (i) compare perennial vs annual crops and irrigated vs rainfed crops in terms of their environmental implications; (ii) identify the main hot spots among adopted agronomic practices that might be responsible for environmental impacts and, as such, might provide useful information to better address choices for farmers and policy makers; and (iii) analyse environmental burdens considering the trade-off with crop productivity considering a dynamic production perspective.
LCT applied	LCA
Assessed crop(s)	Sorghum (Sorghum vulgare Pers.), giant reed (Arundo donax L.), milk thistle (Silybum marianum (L.) Gaertn) and cardoon (Cynara cardunculus L. var. altilis D.C.)
Functional Unit	the functional unit is the cultivated land (one hectare of land) which was chosen to maintain agricultural production while reducing land-use intensity to minimize environmental burdens per area and per unit of time
System boundaries	“From cradle to field gate” approach, this paper aims to evaluate land-based environmental sustainability related to four energy crop options.
Impact categories	ReCiPe method.
Software utilized	SimaPro 8.0.3.14 software
Other information	LCA highlights linkage between crop yield, management, and environmental sphere; Irrigated (rainfed) annual crops are more damaging than the respective perennials; Except for irrigation, fertilizers had the largest environmental effect in all crops; Environmental burdens increase more proportionally than yield in all energy crops; Results identify no winning crop as environmental burdens depend on site specificity.

3.2.2 Environmental life cycle costing (E-LCC)

Environmental-LCC assesses costs directly covered by one or more actors during the life cycle of a product and can internalize externalities (De Menna et al., 2018; Hunkeler et al., 2008). Although this method is not standardized, it follows the LCA approach to provide an integrated outcome. Results are crucial to engage actors as they utilize the monetization to measure the different costs occurring along the food supply chain.

It has become a growing necessity in the last decades to monitor the cost of assets throughout their entire life cycle to optimize costs, taking into consideration all the cost factors relating to the asset during its operational life; in the case of crops, from seedling to post harvesting processes (Woodward 1997; Kloepffer 2008). The Environmental LCC is conducted in a similar way to LCC, but it adds the cost of externalities such as pollution to the overall costs (Hunkeler 2008). A literature review was conducted in Scopus, Google Scholar and Web of Science databases, using keywords such as LCC, ELCC, CBA, camelina, oilseeds, wheat, corn or maize, sorghum, barley, sunflower, cotton. The research resulted in 12 documents coherent, summarized in the following pages.

Most of the LCC/ELCC research focused on the utilization of camelina oilseeds as alternative source of biofuel, while CBA was applied to crops as alternative to others in agricultural rotations.

General search summary of the search:

search 1			search 2			search 3		
“LCC" AND	camelina	2	"Life cycle assessment" AND	camelina	0	Cost benefit analysis (CBA)	camelina	2
	oilseed	0		oilseed	0		oilseed	0
	wheat	1		wheat	0		wheat	2
	barley	0		barley	0		barley	0
	corn	1		corn	2		corn	2
	sorghum	0		sorghum	0		sorghum	0
	sunflower	0		sunflower	0		sunflower	0
	cotton	1		cotton	1		cotton	1
	camelina	2		camelina	0		camelina	2
	Mediterranean	-		Mediterranean	-			
	oil			oil				

According to the main findings, we can conclude that:

- Only a few results were found on the application of LCC and ELCC methodology on crops, mostly for Camelina as an alternative biofuel for jet in North America, compared to traditional fossil fuel.
- Camelina oilseed was found to be convenient as cash crop to alternate to wheat and less expensive as alternative for fuel, also considering a reduced impact on the environment.
- Cost benefit analysis was performed for the introduction, or adoption of GM crops, alternative to fallow for fields, or as potential feeding crops in poor areas.

Below, a summary of the literature review that was performed:

Title and authors	Intensification of dryland cropping systems for bio-feedstock production: Evaluation of agronomic and economic benefits of Camelina sativa
Geographic area	Northern Great Plains, United States of America
Aim of the Research	Evaluation of agronomic and economic benefits of Camelina sativa
LCT applied	LCC
Assessed crop(s)	Camelina, Wheat, Barley, Fallow
Functional Unit	1 Kg of Camelina sativa seeds
Impact categories	Seed and treatment (fungicide)/ Herbicide cost/Fertilizer cost/Farm operations (seeding, spraying and harvesting)

Title and authors	Technoeconomic analysis of camelina oil extraction as feedstock for biojet fuel in the Canadian Prairies Mupondwa, E Li, X Tabil, L Falk, K Gugel, R, 2016
Geographic area	Canadian Prairies of Saskatchewan, Canada.

Aim of the Research	Technoeconomic analysis of commercial extraction of camelina oil as an aviation fuel feedstock, to understand its potential.
Assessed crop(s)	Camelina sativa
Functional Unit	1 Kg of Camelina sativa seeds
System boundaries	100–200 km radius of the 763,000 summer fallow ha of the Brown soil zone
Impact categories	capital cost independent of feedstock costs
Software utilized	Superpro Desginer

Title and authors	Life-cycle energy, GHG and cost comparison of camelina-based biodiesel and biojet fuel, Namrata Dangol, Dev S. Shrestha & James A. Duffield, 2017
Geographic area	State of Washington, United States of America
Aim of the Research	The study aims at comparing lifecycle energy, environmental impact and economic performance of making biodiesel versus biojet fuel from camelina oil.
LCT applied	Cost comparison, cost Benefit analysis
Assessed crop(s)	Camelina sativa
Functional Unit	1 kg of Camelina Oil
System boundaries	Agriculture, Seed transport, Crushing, Oil transport, Transesterification, Biodiesel transport, Combustion.
Impact categories	Market price, cost of oil production, cost of electricity, cost of feedstock.
Software utilized	Cost of production
Main limits	Laboratory-scale experiment, no labor cost, nor transportation costs were included.

Title and authors	Is it economically feasible for farmers to grow their own fuel? A study of Camelina sativa produced in the western United States as an on-farm biofuel, Author links open overlay panel Catherine M.H.Keskea Dana L.Hoag Andrew Brandess Jerry J.Johnson, 2013
Geographic area	Eastern Colorado, United States of America
Aim of the Research	The paper models the economic feasibility of growing the oilseed crop Camelina sativa in the western United States to produce value-added protein feed supplement and an SVO (straight-vegetable oil)-based biofuel.
LCT applied	Stochastic crop rotation budget and profitability sensitivity analysis
Assessed crop(s)	Camelina sativa
Functional Unit	1 kg of Camelina seeds. 1 litre of Camelina Oilseed
System boundaries	Farm level
Impact categories	Seeding costs, Herbicide costs, Labour costs, Fertilizer application costs, Cleaning/crushing/filtering costs, SVO storage costs, Seed hauling costs, Wheat opportunity cost, Loan interest, Offset diesel purchases , Sale of camelina meal Yield
Software utilized	Stochastic crop rotation model, Simetar (Simulation and econometric models for probabilistic forecasting and risk analysis).
Main limits	Limited published information regarding costs for oil crushing, as the western U.S. camelina refining values are not widely available

Title and authors	Life Cycle Based Evaluation of Environmental and Economic Impacts of Agricultural Productions in the Mediterranean Area, Elena Tamburini *, Paola Pedrini † , Maria Gabriella Marchetti † , Elisa Anna Fano † and Giuseppe Castaldelli, 2015
Geographic area	Mediterranean area, Padana Plain, Emilia Romagna, Italy
Aim of the Research	The aim of the research is to evaluate the main cost drivers—environmental and economic—of five widely diffused and market-valued agricultural productions (organic tomato and pear, integrated wheat, apple and chicory)
LCT applied	LCC
Assessed crop(s)	organic tomato and pear, integrated wheat, apple and chicory
Functional Unit	1 kg of wheat, 1 ha of arable soil
System boundaries	From seeding to delivery to the local agricultural consortia. Boundaries included also materials and machineries production, fertilizers and pesticides life cycles, packaging management and resources (energy/fuel/water) production, transportation, and consumptions
Impact categories	Overheads, energy and water costs, materials, labour costs
Software utilized	SimaPro
Main limits	Default data for agricultural processes are limited in LCA database, compared to industrial processes

Title and authors	Benefit cost ratios of organic and inorganic wheat production in Haryana: A case study of Rohtak district, Akshu, 2 Dr. Lalit Sharma, 3 Adesh Hooda, 2017
Geographic area	Haryana, India
Aim of the Research	Aim of the research is to examine rends in the geographical designated area for production and whether farmers should shift to organic production
LCT applied	BCR (Benefit cost ratio)
Assessed crop(s)	Wheat
Functional Unit	1 kg of wheat seeds
System boundaries	Farm
Impact categories	Total production cost, Land preparation cost, Cost of irrigation, Cost of seeds, Labour cost (manual + machine), Fertilizers manure cost, Pesticides organic plant protection cost, Other costs of inputs (transportation and marketing)

Title and authors	Comparative study of life cycle environmental and economic impact of corn- and corn stalk-based-ethanol production Jingmin Hon, Jing Zhou,2 and Jinglan Hong
Geographic area	China
Aim of the Research	The research aims at estimating the economic and environmental impact of corn stalk-based ethanol production.
LCT applied	LCA, LCIA, LCC
Assessed crop(s)	Corn
Functional Unit	1 t ethanol production
System boundaries	road transport, coal-based energy generation, ethanol production, and waste disposal processes
Impact categories	Energy consumption, Feedstock collection, Raw materials consumption, Wastewater, Solid waste to landfill, Waste air
Software utilized	IMPACT2002þ method+ ReCiPe midpoint (E) method

Main limits	limited cost-combined LCAs for grain residue-based ethanol production have been reported in the world. Only one LCA study on grain residue-based ethanol production has been reported in China

Title and authors	Life cycle assessment and environmental life cycle costing analysis of lignocellulosic bioethanol as an alternative transportation fuel, B. Daylan, N.Ciliz
Geographic area	United States of America, Turkey
Aim of the Research	The objective of this paper is to conduct Life Cycle Assessment (LCA) and Environmental Life Cycle Costing (ELCC) studies for lignocellulosic bioethanol blends and conventional gasoline.
LCT applied	LCA, ELCC
Assessed crop(s)	Corn
Functional Unit	1 km driving distance in a midsize car
System boundaries	Feed stock acquisition, bioethanol production, combustion of fuel blends
Impact categories	Acidification, Aquatic eutrophication, Terrestrial eutrophication, Global warming, Photochemical oxidant formation, Stratospheric ozone depletion.
Software utilized	GaBi4
Main limits	Feedstock cost

Title and authors	Cost-benefit Analysis of Corn Production in China, Shi Wen, 2018
Geographic area	China
Aim of the Research	This paper studies the changes of corn production cost and benefit in recent 20 years through specific data in China. And it analyses the effects of fertilizer costs, mechanical action cost, indirect cost, labour cost and government policy on the changes of production cost of maize in China
LCT applied	Cost benefit analysis
Assessed crop(s)	Corn
Functional Unit	1 t of corn
System boundaries	Farm
Impact categories	Material and Service Costs, Labour Cost, Chemical fertilizers, Mechanical operation cost, Depreciation of fixed assets, Tax Insurance, Household labour discount, Number of family's working days, Labour day wages, Mobile land, Proprietary land
Main limits	Land contracting system, lack of organic agriculture

Title and authors	Cost-benefit analysis of conservation agriculture implementation in syrdarya province of uzbekistan, Azizbek Daujanov, Rolf Groeneveld, Alim Pulatov , Wim J.M. Heijman, 2016
Geographic area	Syrdaya, province of Uzbekistan
Aim of the Research	The aim of this article is to investigate the efficiency of CA implementation in the Syrdarya province of Uzbekistan, Central Asia by carrying out a cost-benefit analysis (CBA).
LCT applied	CBA (Cost benefit analysis), Non-Monetized Crop Residue Approach (NMCRA, where benefit of crop residue as mulch was not monetized and therefore excluded from the CBA), Monetized Crop Residue Approach (MCRA), where benefit of crop residue as mulch was monetized and included in the CBA

Assessed crop(s)	Corn, winter wheat, cotton
Functional Unit	50ha
System boundaries	Hypothetical farm, with all the machineries for the conventional agriculture

Title and authors	Economic and Environmental Assessment of Agro-Energy Districts in Northern Greece: a Life Cycle Assessment Approach Emmanouil Tziolas Thomas Bournaris, 2019
Geographic area	Northern Greece Region of Central Macedonia
Aim of the Research	The main goal is the assessment of sustainability based on environmental and economic data and the identification of potential energy generation from crop residues for thirteen major crops in Northern Greece
LCT applied	LCA, LCC
Assessed crop(s)	Corn, hard wheat, soft wheat, and cotton
Functional Unit	1kg of seeds
System boundaries	System boundaries were set to a cradle to gate variation for one agricultural year, from the start of a sowing procedure until the final harvest of produce and biomass derivatives
Software utilized	ABC (Activity based costing) v.1.38.03
Main limits	lack of an integrated coordination plan for the exploitation of renewable energy feedstocks and the absence of farmers' awareness

Title and authors	The Sustainability Price: expanding Environmental Life Cycle Costing to include the costs of poverty and climate change, Murray R.Hall
Geographic area	India
Aim of the Research	The SP addresses research gaps for integrating social and environmental values as well as computational methods in Environmental Life Cycle Costing (ELCC).
LCT applied	Leontief price model, ELCC
Assessed crop(s)	Cotton
Functional Unit	1 T-shirt
System boundaries	From cotton harvesting to t shirt selling
Impact categories	the cost of basic needs for a family by location, the cost of food for a basic but nutritious diet for a family by location, the cost of housing to meet a basic health standard for a family by location , a cost margin for unforeseen events for a family by location, the gross living wage by location, full-time equivalent workers per family by location, statutory payroll deductions and tax by location, the living wage gap by location, the existing gross wage by skill, gender and location.

3.2.3 Social life cycle assessment (S-LCA)

S-LCA is a methodology that aims at assessing the social impacts of products, with the ultimate goal of improving human well-being: the outcomes support the adoption of well-informed choices. S-LCA is still in at early stage in its development, due to the limited case studies associated with the complexity of identifying appropriate and reliable social indicators.

S-LCA is seen as a novel aspect in product or process sustainability assessment, and most studies in the agri-food sector refer to dairy farming, production of citrus, sugarcane, and tomato. A literature review was conducted in Scopus database, using keywords such as S-LCA, camelina, oilseeds and specific crop name (wheat, corn or maize, sorghum, barley, sunflower, cotton). Very few results were obtained so the search was refined and extended with the full terminology of "Social Life Cycle Assessment" and in regard to the other already mentioned words, as well as with the word "oil". A total of 17 documents were located, and after revising the scope, aim and specific application of the S-LCA to suggest comparability with the case of camelina and oilseeds, five (5) papers were selected and summarised as it follows.

General search summary of the search:

search 1			search 2		
"S-LCA" AND	camelina	0	"Social Life cycle assessment" AND	camelina	0
	oilseed	0		oilseed	0
	wheat	0		wheat	1
	barley	0		barley	0
	corn	1		corn	1
	sorghum	0		sorghum	0
	maize	1		maize	1
	sunflower	0		sunflower	0
	cotton	2		cotton	2
	Mediterranean	0		Mediterranean	1
	oil	5		oil	13

** repeated among themselves*

According to the main findings, we can conclude that:

- There are limited results on the S-LCA side; however, keywords seem enough for this specific focus highlighting the fact that there is still a lot of research needed to be done from a LCT perspective.
- Palm appeared a few times as well, so even when not exactly an oilseed, it might be considered as substitute on certain aspects (as ingredient of other food products, in biodiesel refinery, etc).
- Impact categories are varied and does not follow a standardized approach nor clear characterization methods
- The challenges of addressing the quantification of qualitative criteria of the S-LCA are highlighted, including the use of generic databases and local context data availability.

Below, a summary of the literature review performed:

Title and authors	Prioritization of bioethanol production pathways in China based on life cycle sustainability assessment and multicriteria decision-making. Authors: Jingzheng Ren, Alessandro Manzardo, Anna Mazzi, Filippo Zuliani, Antonio Scipioni.
Geographic area	China

Aim of the Research	Apply LCSA (life cycle sustainability assessment) in combination with MCDM (multicriteria decision-making, such as AHP and VIKOR methods) to conduct a sustainability assessment of different scenarios for bioethanol production in China.
LCT applied	S-LCA as part of LCSA (life cycle sustainability assessment).
Assessed crop(s)	wheat-based, corn-based, and cassava-based bioethanol.
Functional Unit	1 t bioethanol
System boundaries	Cradle-to-gate (Agricultural crop production, transportation of crops from agricultural centre to plant, bioethanol production, transportation of bioethanol to market, assumed to be at 500km).
Impact categories	Human rights, working conditions, cultural heritage, social-economic repercussion, and governance (they followed a 5step process to assess the social dimension based on linguistic variables from very poor to very good with a scale from 0 to 10, to later transform them into fuzzy triangular numbers and calculate an average performance). 3 final criteria from the impact categories selected from the fist mentioned to be assessed by the experts (social benefits as part of the working conditions category, and contribution to economic development and food security as part of the social-economic repercussion).
Software utilized	Not mentioned for S-LCA
Main limits	Difficulties in assessing the qualitative aspects of S-LCA, and the still developing method it entails, since it uses different criteria as in SETAC, e.g.
Other information	The introduction of the paper highlights the challenges of addressing the quantification of qualitative criteria of the S-LCA, and the use of multidimensional LCSA results into decision making. Results present cassava-based and corn-based as better performing processes, considering that wheat is the most important staple foods in China, hence affecting food security if competing for bioethanol.

Title and authors	Screening potential social impacts of fossil fuels and biofuels for vehicles. Authors: Elisabeth Ekener-Petersen, Jonas Höglund, Göran Finnveden.
Geographic area	The assessment is based in the EU context of fuel use, assessing the cultivation phase of crops to obtain biofuels from Brazil, USA, France, and Lithuania.
Aim of the Research	Carry out a screening assessment of the social and socioeconomic impacts of fuels and biofuels from different origins, and highlight "hot-spots". There was also the interest of apply S-LCA to evaluate the performance of this method in this particular type of study, using the Social Hotspots Database (SHDB).
LCT applied	S-LCA
Assessed crop(s)	Maize, wheat, oilseed (and sugarcane)
Functional Unit	Not mentioned
System boundaries	Cradle to gate (life cycle stages that entail cultivation, refining/processing and transport in the case of biofuels and the equivalent phase for the fossil fuels)
Impact categories	Human rights, labour, health and safety, community, and governance.
Software utilized	SHDB but no specific software is mentioned.
Main limits	Data is generic and therefore it should be used carefully. Within limitations, the authors mention the use of only certain social impact categories, and they were aggregated as in high risk or very high risk without distinguishing one risk is worse than another, and it could vary depending on consulted experts, region, context. One additional aspect is the fact that the study presents the results as if there a

	only a few risks, when the reality is that only few are assessed because of lack of data, as stated by the authors. Besides data treatment, another limitation was the data source (SHDB), since it is roughly divided for some sectors and data is presented at country level, even when there could be significant differences within a same country. This source also presents limitations in terms of included criteria per impact category. Other limitations have to do with the relation of the social criteria when coping the study with policies, since social aspect are covered in a limited way particularly in the policies of biofuels.
Other information	Combination of data sources, in this case SHDB together with on-site specific data and literature reviews are advisable to make a more robust assessment.

Title and authors	Social Assessment of Biofuels. Authors Edgard Gnansounou, Catarina M. Alves (Book chapter).
Geographic area	EU, Brazil, Indonesia, China, Africa, Zambia, Malaysa
Aim of the Research	The chapter had the aim of providing a review of the state-of-the-art of social assessment in the field of biofuels.
LCT applied	S-LCA
Assessed crop(s)	Several as part of the supply chain for biofuels (maize, sugar cane, cassava, wheat, wheatstraw, urban waste, perennial grasses, palm oil, forest biomass, soybean, jatropha.
Functional Unit	Non-specific
System boundaries	Non-specific although reviewed studies seem to consider from cradle-to-gate.
Impact categories	Several depending on the studies the authors considered for this review, ranging from working conditions, to health and safety, occupational accidents, gender balance, education profiles, well-being, food security, rural area development, and other dimension or multidimension categories (land-use which is shared with environmental categories, or energy security).
Software utilized	N/A
Main limits	Novelty and early stages of life cycle, generic data, still scarce available studies, and even inexistent in some cases. The authors also recognize the still existing limitations into integration of the 3 dimensions of sustainability, particularly the social one, into more comprehensive studies.
Other information	The book chapter consider the most developed methodology to assess social issues is S-LCA, still it recognizes it as a novel technique in its “infant stage”, and the most advanced tool for general data analysis is the SHDB. The study highlights as key social benefits the employment, workforce training and education, income generation, and rural development. The negative outcomes entail effects on the rights of smallholder and rural communities, poor working conditions along the supply chains, precarious living conditions for migrant working-force and land use. It also points out into different types of data that define S-LCA as in generic and site-specific data.

Title and authors	Social implications of palm oil production through social life cycle perspectives in Johor, Malaysia. Authors: Khairul Izzuddin Muhammad, Amir Hamzah Sharaai, Mohd Mansor Ismail, Rosta Harun & Wong Siew Yien.
Geographic area	Malaysia

Aim of the Research	"To identify potential social impacts throughout the whole life cycle of palm oil production", through an assessment preformed in five private palm oil mills. Timeframe: October-December 2016.
LCT applied	S-LCA
Assessed crop(s)	Palm oil
Functional Unit	Not mentioned
System boundaries	gate-to-gate from the palm plantations to the mills where crude palm oil is processed.
Impact categories	2 main impact categories with correspondent criteria: Workers (job satisfaction, salary, discrimination, health and safety, social benefits) and local communities (health and safety, cultural heritage, involvement, and job opportunities).
Software utilized	Not mentioned
Main limits	Not expressed in the text, however it is performed for the palm oil production in general and not specifically for life cycle stages, which could have been useful for hot-spot analysis.
Other information	The authors are very specific regarding the data collection tools they used, since they mention the construction of the questionnaires, its validation, piloting and reliability tests, as well as sampling for the stakeholders that were consulted. The results are presented as an aggregated assessment of each impact category for each of the two addressed stakeholders, with no value chain allocation (farming for example). In general, the study presented not only negative impacts but also the importance of the crop and its role in poverty reduction in the geographical area of the study, which is an interesting trait of S-LCA.

Title and authors	Social Life Cycle Assessment (S-LCA) For Palm Oil Production in Malaysia. Authors: Khairul Izzuddin Muhammad, Muhamad Faiz Muhamad Pauzi and Amir Hamzah Sharaai
Geographic area	Gua Musang, Kelantan. Malaysa
Aim of the Research	To identify potential social midpoint impacts throughout the whole life cycle of palm oil.
LCT applied	S-LCA
Assessed crop(s)	Palm oil
Functional Unit	Not mentioned
System boundaries	gate-to-gate, involving oil palm plantation up to the factory process to obtain crude palm oil.
Impact categories	Midpoint impacts from workers and the local community as addressed stakeholder categories in the study.
Software utilized	Not mentioned
Main limits	The authors suggest that further studies should be carried out to include other stages of the life cycle of the product and recommend the need to keep records in order to be able to obtain data for the assessments.
Other information	Very specific information regarding the data collection process (sample, questionnaire, etc).

Title and authors	Prospects of Bioenergy Cropping Systems for A More Social-Ecologically Sound Bioeconomy. Authors: Moritz Von Cossel, MoritzWagner , Jan Lask, Elena Magenau, Andrea Bauerle, Viktoria Von Cossel, Kirsten Warrach-Sagi, Berien Elbersen , Igor Staritsky, Michiel Van Eupen, Yasir Iqbal, Nicolai David Jablonowski, Stefan Happe, Ana Luisa Fernando, Danilo Scordia, Salvatore Luciano Cosentino, Volker Wulfmeyer, Iris Lewandowski and Bastian Winkler
Geographic area	Europe
Aim of the Research	To investigate how bioenergy cropping systems (BCS) can become more social-ecologically sustainable in future.
Methods	Social approach. Experts opinions from the fields of agronomy, economics, meteorology, and geography
Main limits	Socio-economic considerations in the studies, since even when it is mentioned, most of the focus is agronomic and environmental.
Other information	Potential solutions to the following five main requirements for a more holistically sustainable supply of biomass are summarized: (i) bioenergy-crop cultivation should provide a beneficial social-ecological contribution, such as an increase in both biodiversity and landscape aesthetics, (ii) bioenergy crops should be cultivated on marginal agricultural land so as not to compete with food-crop production (iii) BCS need to be resilient in the face of projected severe climate change effects, (iv) BCS should foster rural development and support the vast number of small-scale family farmers, managing about 80% of agricultural land and natural resources globally, and (v) bioenergy-crop cultivation must be planned and implemented systematically, using holistic approaches The paper recognizes the applicability of LCA, however it considers several aspects are still missing, such as soil quality, the impact of different agricultural systems on the biodiversity and the effect of crop rotations. It suggests the integration of socio-economic approaches beyond cost assessments, including externalities such as subsidies related to emissions and ecosystem services. It considers Life Cycle Sustainability Assessment can aid into that last focus, particularly due to the chances of including several stakeholders in the assessment.

Title and authors	Socio-economic impact assessment in rural development--case study Camelina production in Romania. Authors: Delia Dimitriu, Dumitru Moldovan, Petru Stefan Runcan, Raluca Calauz
Geographic area	Romania. Sanmartin Commune from Cluj County, comprising 8 villages
Aim of the Research	To identify the relevant social and economic aspects, to assess the potential development impacts associated to Camelina production and propose a SEIA (Socio-Economic Impact Assessment) framework presented in the ITAKA (Initiative Towards sustainable Kerosene for Aviation) project.

Methods	SEIA (Socio-Economic Impact Assessment) framework, following the SEIA Guidelines by MacDonald, 2006. It included a baseline survey and used a mix methodology (quantitative and qualitative).
Main limits	The researchers indicate that social change is difficult to quantify (in contrast to economic changes), since the assessment relies on the perceptions of residents about the proposed development. They address it through interviews.
Other information	The SEIA includes economic prosperity and social development, which leads to an increased quality of life. Surveys were based in these pillars: Existing local regulations and stakeholders involved, Local ownership and involvement, Taxation policy at local, regional, national and EU level Selected villages and consideration, Assessing and Quantifying Socio-Economic Impact at local level; represent benefits, profits due to Camelina production versus risks vulnerability. Main benefits are represented by increased employment and living standards, increased social cohesion and stability for rural communities. The increase of the crop could also include negative impacts, such as adverse impact upon existing farming activities, biodiversity losses and congestion on local roads and in communities due to increased traffic. From the stakeholder´s point of view, workers considered the increased chances of obtaining jobs, farmers saw as positive the less intensive need of inputs and mechanisation specialization from the needed machinery. The community and its leaders saw an opportunity of an increase in local tax collected, economic diversification and the development of better services (more local consumption and available income to spend. Local authorities see additional benefits in promoting rural development and reducing urban migration. Authors mention that "An understanding of local conditions and local culture is critical not just to ensure engagement from stakeholders, but also to design an appropriate SEIA framework and maximise opportunities for securing the appropriate data to provide meaningful outputs".

3.2.4 Life cycle sustainability assessment (LCSA)

LCA, S-LCA and LCC are designed to provide a full life cycle sustainability assessment outlook, which refers to the evaluation of all environmental, social and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle (UNEP-SETAC, 2009; UNEP, 2011).

Even when this WP is not expected to perform a fully integrated LCSA, certain integration according with data outcomes – due to data availability and quality – could be made. However, results coming from the performance of consequential LCA, E-LCC and S-LCA in the selected cases based on field trials and pilots, would provide an overall view of the potential results of the adoption of Camelina in current systems, for the three dimensions of sustainability (the environmental, the economic and the social); therefore, sustainability remains the main focus of the assessment in this framework. Moreover, a crop system management perspective, modelling the variability brought by the variables from the trials (tillage type, seed density, sowing period and fertilization, depending on the model) will allow the assessment of scenarios undertaking the LCT triple-bottom approach.

4 Main conclusions

4.1 LCT elements to conduct the assessments

Both the literature review carried out for Deliverable 4.1, and the development of guidelines and protocols in other WP guides towards the different elements were considered to conduct this life cycle thinking assessment framework on 4CE-MED systems. It is needed to define a final aim of the camelina utilization to maintain consistency with the goal and scope of the assessment. In this sense, the function of camelina (crop to introduce CA practices, or to obtain oil, or to be used as feedstock) will be clearly defined. This later would influence the selection of two elements: system boundaries and functional unit. Literature presented the options to perform cradle-to-farm gate studies, as well as cradle-to-factory gate studies, when assessing the use of camelina for oil. It would also suggest the possibility to perform the assessment based on mass functional units (t seeds, t fresh harvested camelina; or t, Mg or L of oil), energy functional units (MJ from biodiesel or GJ of energy content), or spatial units (ha of arable land used in the crop). In other cases, the systems can be assessed for the use of the final product, in terms of km of car travel with the produced biofuel, hence adapting the system boundaries. Impact categories would most of the time refer in the environmental dimension to midpoint categories, with the consistent use in most of the studies of at least the Global Warming Potential, Eutrophication Potential and Terrestrial Acidification Potential. Regarding the economic dimension, most LCC studies used cost categories related to inputs, operational expenses, capital, services, and in one case included the market value. Finally, the social dimension includes impact categories that range from endpoint to midpoint categories, where human rights, working conditions and community are most addressed, together with particular ones as cultural heritage, health and safety and governance. These impact categories set the base for the selection for the 4CE-MED models' assessment, in consonance with the overall objectives of the project.

As per the 4CE-MED models, cradle-to-farm gate models for the cropping system with functionality based mostly on yield will be considered in culture succession is considered. The functional unit is expected to be mass- based. The environmental dimension will refer to midpoint categories, with a consistent use as in most of the studies of Global Warming Potential, Eutrophication Potential and Terrestrial Acidification Potential, at least. The cost categories, income and net margin will be observed in the economic dimension, and impact categories related to farmers, workers and community stakeholders are to be addressed in the social dimension.

4.2 Basic considerations required for data collection

Main elements are already presented to move forward into the data collection and future steps of the LCT approach in terms of inventory analysis, impact analysis and interpretation of results. The data collection protocol will be detailed in Deliverable D4.2; however close coordination with partners and WP will be required to avoid duplicity or gaps in the collected data. For instance, Experimental Protocols in WP2 already consider the measurement of harvested biomass, as well as harvested product characteristics which would aid into the yield assessment required for FU-related calculations, among others. On the other hand, particular data from the trials and local current and trial systems will be required to perform the inventory phase, i.e. amount and cost of inputs, labour, amount of outputs (not only harvest).

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