Advanced Sustainable BIOfuels for Aviation

Deliverable D4.4

Final Report on the assessment of environmental sustainability indicators for advanced biojet fuel value chains on marginal lands in the Mediterranean (Task 4.3)

Consortium:

Acronym	Legal entity	Role
RE-CORD	CONSORZIO PER LA RICERCA E LA DIMOSTRAZIONE SULLE ENERGIE RINNOVABILI	CO
ENI	ENI S.p.A.	BEN
SKYNRG	SKYENERGY BV	BEN
CENER	FUNDACION CENER-CIEMAT	BEN
ETA	ETA – Energia, Trasporti, Agricoltura Srl	BEN
CCE	CAMELINA COMPANY ESPANA S.L.	BEN
JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION	BEN

CO…Coordinator, BEN…Beneficiary

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Document Type		
PRO	Technical/economic progress report (internal work package reports indicating work status)	
DEL	Technical reports identified as deliverables in the Description of Work	**x**
MoM	Minutes of Meeting	
MAN	Procedures and user manuals	
WOR	Working document, issued as preparatory documents to a Technical report	
INF	Information and Notes	

Dissemination Level		
PU	Public	**x**

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1. Summary

The present deliverable contains the activities related to the following tasks:

- "GIS data of potential Camelina feedstock production on marginal lands in EU MED area"
- "Environmental sustainability of feedstock potential production on marginal land assessed through the measurement of environmental sustainability indicators (soil properties, water use and efficiency, soil biodiversity proxies, and land use change)".

This work develops around the modelling exercise performed on the prediction of Camelina yields in rotation with Barley in Mediterranean marginal land in the D2.7 deliverable: Assessment of potential for drought-resistant oil crop in marginal land of Southern Europe and abroad.

Bioenergy oil crops, and specifically Camelina, have the potential to be grown profitably on marginal lands and can therefore offer a source of income to local farmers and related industries while helping to achieving the targets of the Renewable Energy Directive (EC/2009) and Directive (EU) 2018/2001. Bioenergy can contribute to the energy resilience of a country. The geographic information systems (GIS) analysis has highlighted the more productive NUTS2 (Nomenclature of territorial units for statistics) which are considered the basic regions for the application of regional policies, under cropland land use, and the scenario analysis has found potential non-conflictual land where it is profitable to establish cereal-oil crop rotations for food and energy purposes. The objective of the BIO4A project, funded by the EU's Horizon2020 programme, is to support the implementation of sustainable feedstock production for biofuels in EU marginal land. We applied spatial multi-criteria decision analysis techniques in GIS to generate a land suitability assessment at 500-m spatial resolution considering the elevation, slope, topsoil soil organic carbon and average precipitation , which has produced the following classes of Camelina cultivation suitability:

- Very high (>75%)
- High (60% - 80%)
- Moderate (40% - 60%)
- Low (20% - 40%)
- Very low (<20%)

GIS mapping of potential Camelina feedstock production on marginal lands in EU MED area identifies the potential suitable locations based on the current CORINE (CLC) land cover classes with three possible scenarios consisting of the

- extent of land cover rainfed crops (CLC 211);
- land covers that contain a mix of rainfed crops and marginal underutilised land (CLC 241,242,243);
- total area for the cultivation which contains rainfed cropland and marginal underutilised land (CLC 211,241,242,243,).

The Environmental sustainability (ES) of feedstock potential production on marginal land is assessed through the application of a Convergence of Evidence (CoE) methodology and a set of environmental sustainability indicators:

- **Soil Erosion** (Panagos et al., 2015)
- **Soil Compaction** (Gergely Tóth, Luca Montanarella, 2015)
- **Nitrogen inputs** (de Vries et al., 2021)
- **Soil biodiversity** (Orgiazzi et al., 2016)
- **Aridity index** (Zomer et al., 2022)

This has been overlaid to the potential Camelina yield considering its rotation with barley (Deliverable 2.7).

While agricultural soils are important everywhere, the analysis helps identify the places that are among the most critical for local communities, and nearby potential. There is a need for sustainable no-food-competing feedstock for hydroprocessed esters and fatty acids (HEFA) production: in this respect, the EC REDII Directive has indicated a possible route in so-called low-ILUC biofuels[1]. This option will mostly translate in exploiting marginal lands with

1 **Consolidated text: Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance).**

new drought-resistant no-food or dedicated crops, to develop a long-term strategy that increases soil resilience towards climate change and desertification.

This is particularly true in the southern Mediterranean region, where strong evidence exist of land degradation effects, as depicted in the recent publication (Schillaci et al., 2022a) on land degradation assessment using the Sustainable Development Goal (SDG) 15.3.1 indicator in the EU27. Under these circumstances, changes of land cover, loss in vegetation productivity, loss of soil organic carbon are triggering consequences that, in extreme cases, will lead to desertification. Results from the land degradation (LD) assessment study based on the UN SDG 15.3.1 indicator at EU27 scale using the high-resolution land productivity, land cover and SOC stock changes indicate that degradation trends are evident in 23% of the area, followed by 69% under stable condition, and 7% of the area with improving conditions. The SDG 15.3.1 indicator can recognize a part of the ongoing potential LD issues but does not always capture the severely degraded land. There is need to take action before further land is irreversibly lost, in particular in Spain, Portugal, Italy and Greece, as well as in the southern rim of the Mediterranean basin.

The BIO4A project has developed a strategy for the valorization of drought resistant crops in marginal lands of Southern EU. The action is composed by three main pillars: 1) the use of organic amendments such as compost from biomass anaerobic digestion sludge; 2) the use of biochar obtained by the pyrolysis of agricultural/forest residues to increase soil resilience to climate change; and 3) the cultivation of selected varieties of drought resistance oil crops (e.g. *Camelina Sativa L. Cranz*) suitable for aviation fuel production.

This approach has never been tested in the aviation biofuel chain in Southern EU/MED soils, and is fully in line with the proposed EC Directive 2018/2001 (REDII), the SDGs targets on land degradation and climate change mitigation, and the EU's roadmap to a Resource Efficient Europe, which aims at no net land, take by 2050. Moreover, if successful, this approach can be replicated in many EU areas and other parts of the world experiencing the same conditions due or in response to climate change.

The amount of marginal land in the EU28 was estimated at 18.3 Million of ha by the EU FP7 project S2Biom. In addition to the production of sustainable fuels for aviation, the proposed solutions will also play a role in C sequestration, as biochar is mainly fixed carbon that will remain in the soil for hundreds of years: this is in line with the Paris COP21 indication to develop Carbon Negative actions and not just Carbon Neutral ones. Furthermore, the cultivation of feedstock will open new avenues for Mediterranean agroecosystems that in the last decades have seen a consistent rate of land abandonment expecting that marginal agricultural land will evolve into shrubland due to wood encroachment which will reduce their productivity.

General objectives of the project

Decarbonizing & reducing aviation dependence on fossil fuel requires sustainable biofuels. Considering that, the steady grow of the aviation industry and the aim of reducing the emission by 50% in 2050 is becoming indispensable to find viable solution such as the adoption of Sustainable Alternative Fuels (SAF) (Panoutsou et al., 2021). However, today SAF are available only in rather small amounts compared to the jet fuel demand. It is therefore vital to scale up commercial production in Europe (Chiaramonti and Panoutsou, 2019). Furthermore, the scalability of the HEFA pathway (the main commercial pathway as of today) is limited, due to constrained availability of truly sustainable feedstock sources. Bio4A therefore defined two main objectives for the action:

1. Increase EU installed capacity and supply, and prove SAF production on commercial scale in Europe with residual lipids

2. Develop Low-ILUC feedstock strategies to increase the potential supply of EU sustainable lipids to HEFA pathway.

The use of LCA will allow evaluating SAF chain in order to prove greenhouse gases emissions reduction compared to fossil Jet A1 of at least 60%. Expected social impacts will be assessed for human and labor rights, rural and social development, number of jobs created, among others.

2. GIS Biophysical constraints identification for rainfed crop cultivation in the Mediterranean area

2.1 Land suitability assessment

The potential for the cultivation of energy crops for biofuels production can be determined by an evaluation of the main biophysical factors such as topography, climate, soils as well as economic factors (farm distance to transportation networks and refineries and processing plants, level of agricultural mechanization, crop rotation, irrigation) in a GIS framework consistently with the scale of investigation. Often, logistical aspects of the post-harvest are not taken into account. The BIOPLAT-EU project provided web-GIS to map suitable marginal and underutilized contaminated lands for sustainable oil crop production at pan-European level where refineries and biomass conversion plans are available to take into account the logistic aspects. The objective of BIO4A project consider the future need to SAF supply for the aviation sector. The scenario adopted consider the steadily production of feedstock with the cultivation of Camelina (*Camelina sativa L. Cranz*) in rotation with Barley. A Multi-Criteria Decision Analysis (MCDA) in a GIS framework that provides soil, land cover, terrain and climate traits was adopted to define the overall suitability at a 500m pixel scale in southern European areas. The MCDA adopted to support decision-makers, analyse a set of alternative indicators and uses decision rules to aggregate the criteria, which allows the alternative solutions to be ranked or prioritized. The MCDA provided a general framework to operate a suitability mapping by relating agro-ecological parameters. It consisted in the definition of an area based on climate pattern, previously cultivated agricultural land cover (CORINE), soil texture, fertility (SOC percentage based on LUCAS soil survey) and soil bulk density to define the main local condition for the crop modelling scenarios (Figure 1).

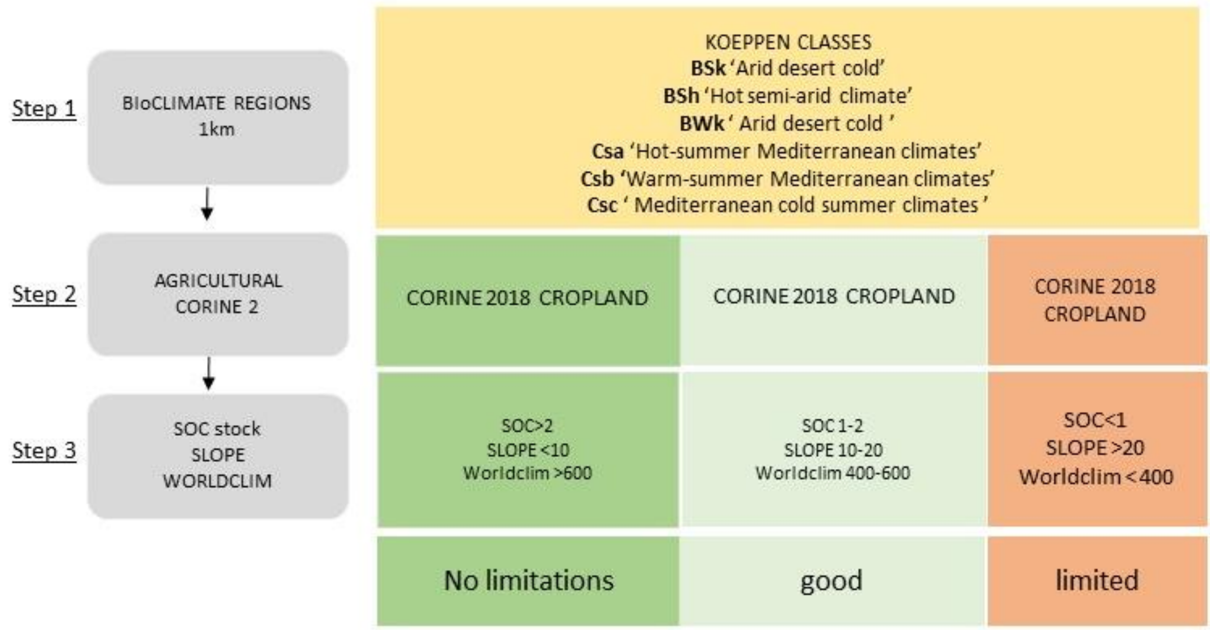

Figure 1 Climate, land cover and biophysical parameters taken into account to define the study area.

2.2 Climate classification - Köppen climate zones

The Köppen-Geiger climate classification (Chen and Chen, 2013; Rubel and Kottek, 2010) was developed based on the empirical relationship between climate and vegetation. This climate classification scheme provides an efficient way to describe climatic conditions defined by multiple variables and their seasonality with a single metric. This classification is used in ecological modelling and for agronomy purposes, to define homogeneous zones for both conservation and management. Many examples of its use are found in literature for mapping geographic distribution of long-term mean climate and associated ecosystem conditions. Recently, there was an increasing interest in using the classification to identify changes in climate and potential changes in vegetation over time. This work used a Köppen dataset developed by (Beck et al., 2018) to map potential semi-arid areas for Camelina production in the Mediterranean Region of the EU. The most widespread class is the dry climate (B) in which the controlling factor on vegetation is dryness, which is defined by the relationship between the precipitation input to the soil in which the plants grow and the evaporative losses. Since evaporation is difficult to evaluate and is not a conventional measurement, aridity is defined in terms of a temperature-precipitation index. To meet these conditions the total annual precipitation is less than 10 times the dryness threshold accompanied by a significant area of mild temperate, with a coldest month temperature greater than -3 °C and less than +18 °C climate (E), which have practical and theoretical implication.

In particular three classes of dry climates were identified as suitable:

- **Bwk** Total annual precipitation is less than or equal to 5 times the dryness threshold. Annual mean temperature less than +18 °C (i.e. generally cold, dry winters).
- **Bsh** (semi-arid) which has a total annual precipitation is greater than 5 times the dryness threshold annual mean temperature is greater than or equal to +18 °C (i.e. hot, dry summers and cool, humid winters).
- **Bsk** (semi-arid) which has a total annual precipitation greater than 5 times the dryness threshold. Annual mean temperature is less than +18 ° (often found bordering Bsh, with warm, dry summers and cold, humid winters).

In addition, we also find occurrences of dry temperate climates (C), with two classes of interest:

- **Csa**, Mild temperate with dry summer, driest month precipitation in summer is less than driest month in winter, wettest month precipitation in winter is more than three times the driest month precipitation in summer, and driest month precipitation in summer is less than 40 mm, Warmest month temperature is greater than or equal to +22 °C.
- **Csb**, Mild temperate with dry summer, coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 40 mm (1.6 in).
- **Cfa**, Different from Cs and Cw, defined as mild temperate, fully humid. Warmest monthly temperature is greater than or equal to +22 °C.

2.3 CORINE Land cover

Traditionally, human activity has shaped our landscape, with an impact on the environment. Natural capital entail land resource used for multiple purposes: agriculture, mining, manufacturing and construction, transport and residential use. The effects of overexploitation have changed natural vegetation to cropland and pastures, and sometimes the signs of desertification are visible in certain EU regions. Global warming has contributed towards increasing awareness and recognition that land provides many ecosystem services, and it is a limited resource. The Corine land cover (CLC) is a pan-European inventory of land cover coordinated by the European Environment Agency. It provides a biophysical classification of artificial areas, agricultural areas, forests and semi-natural areas, wetland and water bodies. In this work, the dataset for 2018 is used to select all the agricultural areas that could be suitable for the production of Camelina. This layer is made up of several classes, including rainfed cropland (Corine code 211), fruit and trees (Corine code 223) and complex agricultural patterns (Corine code 241), where the interpretation of the spectral information denoted a mixture of agriculture and natural vegetation. A high proportion of the EU's territory, 40%, is used for agriculture (EUROSTAT, 2021).

2.4 LUCAS Soil data, texture, Soil organic Carbon and Bulk Density

The Land Use and Coverage Area frame Survey (LUCAS) has collected statistical information on land use and land cover over the territory of the EU from 2006. In 2009, a soil component (LUCAS Soil) was added. The soil sampling follows a complicated sample design, based on the random stratified sample of the field verification points of the main survey. Soil samples and supporting data were collected by direct observations of about 22,000 points (a similar number were also collected by the 2015 LUCAS survey) by surveyors on the ground (in situ). The initial objective for the LUCAS Soil survey was to collect data on soil organic carbon (SOC), with emphasis on agricultural soils. Over time, the scope of the LUCAS Soil survey was broadened and additional parameters were collected and analysed. For the chemical and physical laboratory analysis, composite sample of approximately 500 g are taken from five subsamples collected with a spade at each LUCAS point. The first subsample is used to report the location coordinates, the other four subsamples were collected at a distance of 2 m following the cardinal directions (North, East, South and West). In the exact place of sampling, stones (>6 cm) (FAO, 2006), plant residues, grass and litter were removed from soil surface by raking with the spade. The five subsamples in the bucket were mixed with a trowel. Aliquots (about 500 g) of the mixed soil are taken with a trowel from the bucket, placed in a plastic bag, and labelled to derive the composite sample. Soil samples were allowed to air dry before the bags were sealed. Based on the 2009 data, topsoil texture has been mapped for the EU, (EU 26) with a nominal pixel resolution of 500x500 m (Ballabio et al., 2019). These data are available for the yield model simulation. Furthermore, soil organic carbon data are available from both the 2009 and the 2015 sampling campaign and spatially available at the same resolution of the fine earth fraction (Ballabio et al., 2016). Relatively high values of BD indicate soil compaction which may lead to reduced water infiltration especially in agricultural land, where it can hamper the growth of crop root systems (Schillaci et al., 2021). Soil bulk density (BD) is calculated as the dry weight of soil divided by its volume. Volumes include soil particle volume and pore space between soil particles. Soil BD is typically expressed in g cm^{-3} or Mg m^{-3} (SI). BD is necessary to calculate SOC stocks and is directly linked to soil functionality including mechanical support of crop plants, circulation of soil solution, and soil aeration. In LUCAS soil BD values are derived from packing density data using the equation proposed by (Jones et al., 2003) conditioned by clay content and quantify the meaning of qualitative categories of packing density for mineral soils.

2.5 Topography

Due to the scale of the analysis, the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), with an original resolution of 30 m (Farr et al., 2007), was resampled to 500 meters. This information was used to calculate the additional geomorphometric derivatives of slope and aspect, (using SAGA GIS, Conrad et al., 2015). The derived slope map was reclassified in two classes: slope from 0-15% and >15%. Aspect was reclassified into North (315-45 degrees), East (45-135 degrees), South (135-225), West (225-315).

2.6 Map of the biophysical constraints identification for land suitability assessment

The map of the biophysical constraints map represents a generalized model of land suitability based on environmental factors. Values were assigned to the Slope (1= >15%, 2= <15%,3= 0 %), Soil organic Carbon (1 <1% , 2 1-2.5%, and 3 >2.5%), average annual rainfall taken from WorldClim Bio12 (1= Bio12<400 mm yr-1 , 2 = Bio12 400-700 mm yr-1, and 3 = Bio12 >800 mm yr-1), overlaid in GIS at 500 m pixel scale. The results for the suitability, presented at pixel scale. Previously published reports have described biophysical limitation at European scale (JONES et al., 2014). In this assessment, the morphological and climatic suitability were considered as key elements when evaluating productivity level (yield) for the production of food, feed and energy (JONES et al., 2014). The highest overall suitability will possibly reduce the application of mineral fertilizers input which is extremely important for the production of biomass for energy purposes. The BIO4a project has also tested the application of Biochar and Compost amendments in Camelina-Barley rotation which can offset C losses in sites where the model showed losses due to the cultivation (Blanco-Canqui, 2013). It is therefore of particular interest to evaluate, at local scale, the land resources necessary to support the production of land-based energy sources and the provision of other services, as demanded by the upstream economic and energy models.

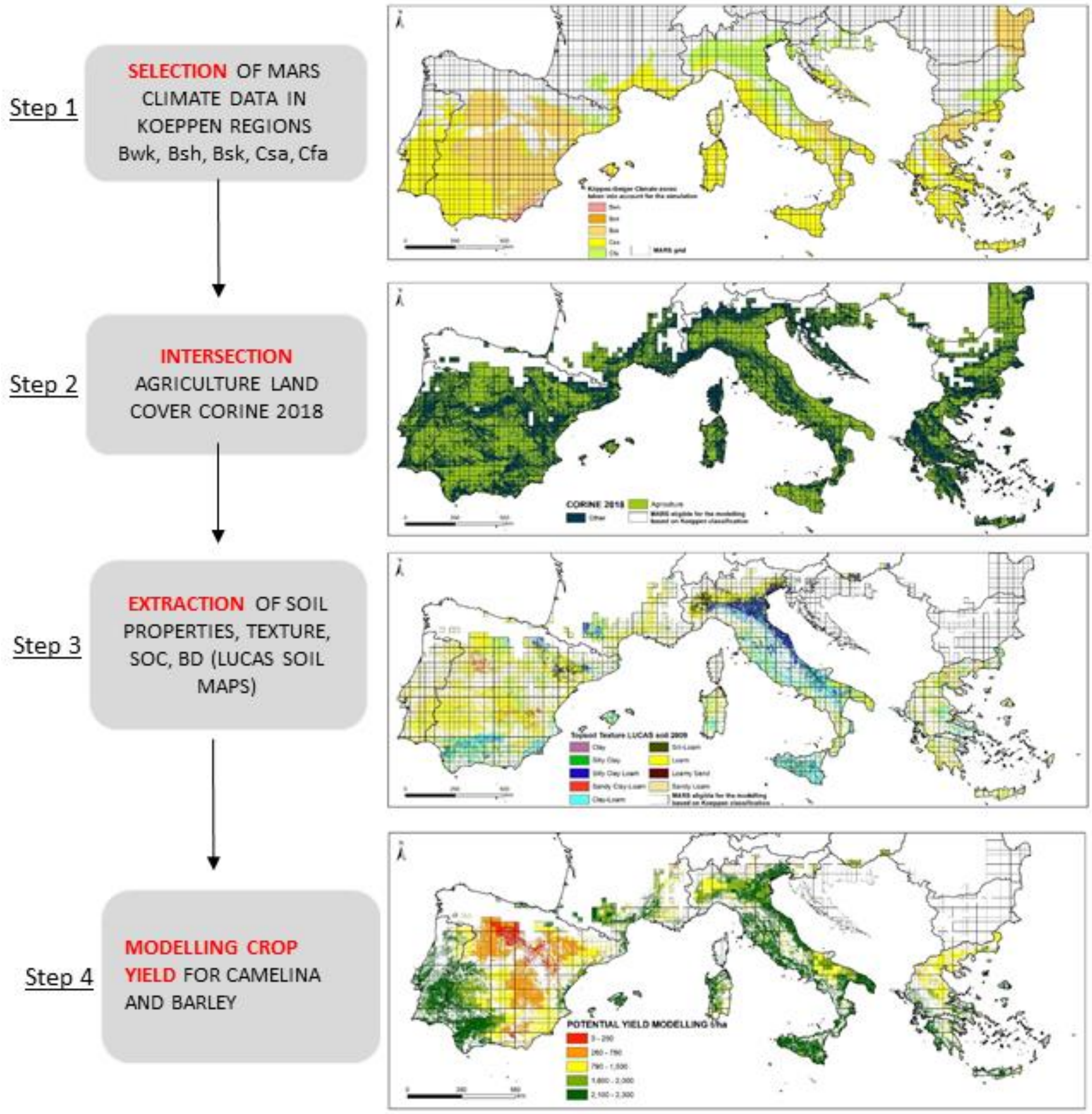

Figure 2 Conceptual diagram showing the four steps performed prior to the simulation using ARMOSA crop model.

The Köppen climatic regions offer a long-term condition of biophysical conditions throughout the seasons. In the step 2, land cover defined the study area inside the climatic region; LUCAS soil properties provided the physical properties and the initial fertility conditions upon which the model calculated the dynamics due to the cultivation.

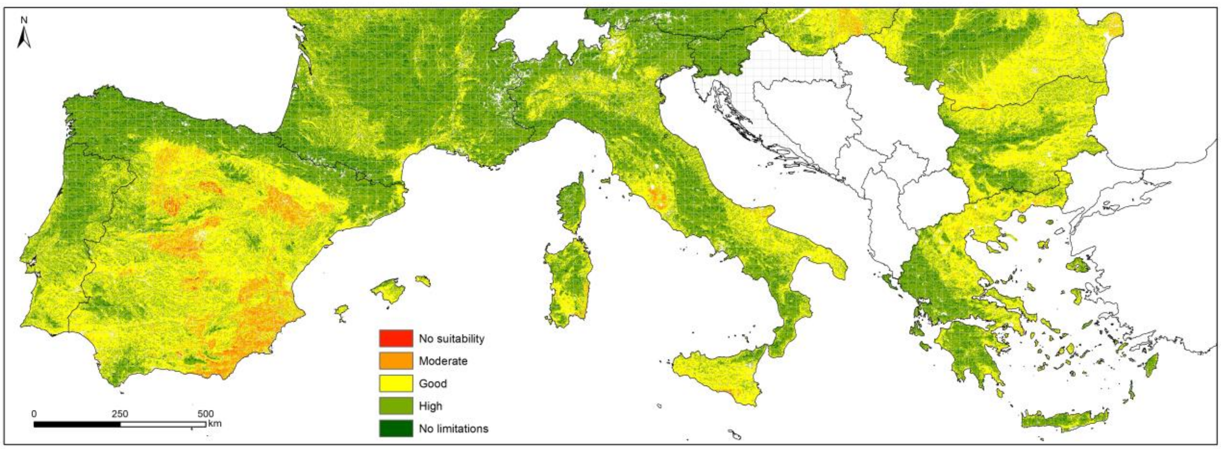

Figure 3 Multi-Criteria Decision Analysis (MCDA) based on biophysical variables.

3. GIS metadata and online repository compilation

To provide a detailed list of sources of the data produced and used to assess the Camelina potential yield in the Southern Mediterranean a template for the metadata was adopted from ESDAC (provided from Marc van Liedekerke).

3.1 Metadata form

Table 1. Metadata template

Field	Description
Metadata compiler	name and email of the person entering the metadata
Identification	Unique identification of the dataset, if available (A UUID, URN, or URI, such as DOI)
Context of dataset	Context, background: e.g. EU-Project XYZ, Data from Literature, National data, Governmental, Research, ...
Title	Short meaningful title
Short description	Short description of dataset
Long description	Longer description or abstract; can include (multiple) scientific/technical references
Soil properties	Soil properties described in this dataset, free text
Soil function	Soil functions described in this dataset, free text
Soil threats	Soil threats described in this dataset, free text
Soil Indicators	Soil indicators described in this dataset, free text
Format	File Format in which the data is maintained or published (e.g. Shapefile, Tiff, Excel); free text
	Features in the dataset (e.g. points, lines, polygons); free text
Spatial resolution	Resolution (grid; e.g. 1km x 1km) or scale (vector; e.g. 1:1,000,000)
File / service Location	Url or path to the data files or services
Geographic extent	Geographical coverage (e.g. EU, EU & Balkan, Country, …)
Temporal extent	Reference period for the data (e.g. 2010, or 2003-2007)
Reference system	Spatial Projection information, if applicable: free text
Status (*)	Status of the dataset; free text and/or value from list
Access constraints (*)	Indicates if the data is publicly accessible or the reason to apply access constraints; free text and/or value from list
Usage constraints (*)	Indicates if there are legal usage constraints (license); free text and/or value from list
Keywords for dataset	Keywords; separated by ';'
Contact for dataset	Name; organization; email; possibly role (distributor, owner, pointOfContact, processor, publisher, metadata-contact)
Sources	Sources are references to other dataset which are used as a source for this dataset
Lineage	Statement on the origin and processing of the data, if known; also a statement of quality or any other supplemental information relative to the data

Language	Language, of the data and metadata, if metadata is multilingual multiple languages can be provided
Citation	Citations are references to articles which reference this dataset; multiple lines in the field possible; one citation on each line; Title; Authors; Date; or provide a DOI
Maintenance frequency (*)	Indication of the frequency of data updates; free text and/or value from list
Modification date	Date of last modification of dataset, free text

3.2 Data availability via the ZENODO platform

The GIS data from the modeling exercise carried out for Camelina in rotation with Barley are made available along with metadata in the Zenodo platform and after the publication of the peer review paper in the European Soil Data Centre ESDAC webpage.

4. GIS Camelina yield modelling results and marginality assessment via yield thresholds

Cultivation of bioenergy crops has the potential to release or capture carbon dioxide (atmospheric CO_2) as a consequence of land-use changes (LUC). These events are caused by the exchange of biomass, soil and organic waste contained on and within the land. In some cases, these emissions may dominate the GHG life cycle of the biofuel route. According to Plevin at al., (2010), land-use changes can be divided into i) direct land-use change (dLUC), referring to the change of land of natural vegetation to agriculture, or from a specific cultivation to another one causing a change in the capacity of the land; and ii) indirect land-use change (iLUC), referring to the change of land produced by the cultivation of certain biomass, that is, outside the boundary of the system being assessed also known as the "butterfly effect" (Escalante et al., 2022). This usually occurs when dLUC replaces a raw material already on the market, so an attempt is made to make up for the deficit. The magnitude of the emissions generated by the LUC will depend on the type of land converted into a cultivation field and the type of seed to be cultivated. dLUC also involves the conversion of land for the construction or conversion of biorefineries for the production of biofuels.

The Camelina seed yield is the main source of supply, which is determined by the area harvested (acreage) and yield per hectare. The cultivated area with oil crops, which generally reflects the net return to farmers who grow food, was experienced a rising in the EU during 1990s and 2020s[2] but to avoid competition with the food crops is becoming imminent and land is approaching the maximum capacity (Gelfand et al., 2013). Factors such as climate and weather conditions mainly affect agricultural yields (Bregaglio et al., 2014; Filippi et al., 2019; Masselink et al., 2016). Higher temperatures may not only reduce the time farmers spend in the field (Zhao et al., 2021), but may also cut down grain yields owing to water shortages and higher evaporation rates (Dumortier et al., 2021). Apart from this, for heatwaves (Fabri et al., 2022) noted that this factor may not affect farmer as well as average warming. Temperature and precipitation as easily obtainable weather factors are often available at coarse spatial scale (10 to 100 km) for the continental scale. The use downscaled meteorological data to estimate yields in most cases result in no statistical differences from observations and therefore average simulated yield derived from downscaled data are suitable for regional scale mapping (Cammarano et al., 2013). The identification of potentially suitable lands for Camelina production was undertaken based on the integration and analysis of different spatially explicit factors compiled in a GIS environment. The spatial suitability analysis was derived from the crop modelling results (Schillaci et al., submitted) from: i) the simulations values achieved by calibrating the ARMOSA crop model were obtained by real field experiments retrieved in published peer review papers; ii) the meteorological daily data from the Gridded Agro-Meteorological Data in Europe; selected soil traits derived from LUCAS soil module (Soil organic carbon and soil texture) and environmental factors such as Slope and Aspect.

Marginality was recently framed as a dynamic concept in time and space (Csikós and Tóth, 2023). The changing meaning of marginal land can be managed by choosing the right agronomic technique and conservation agriculture

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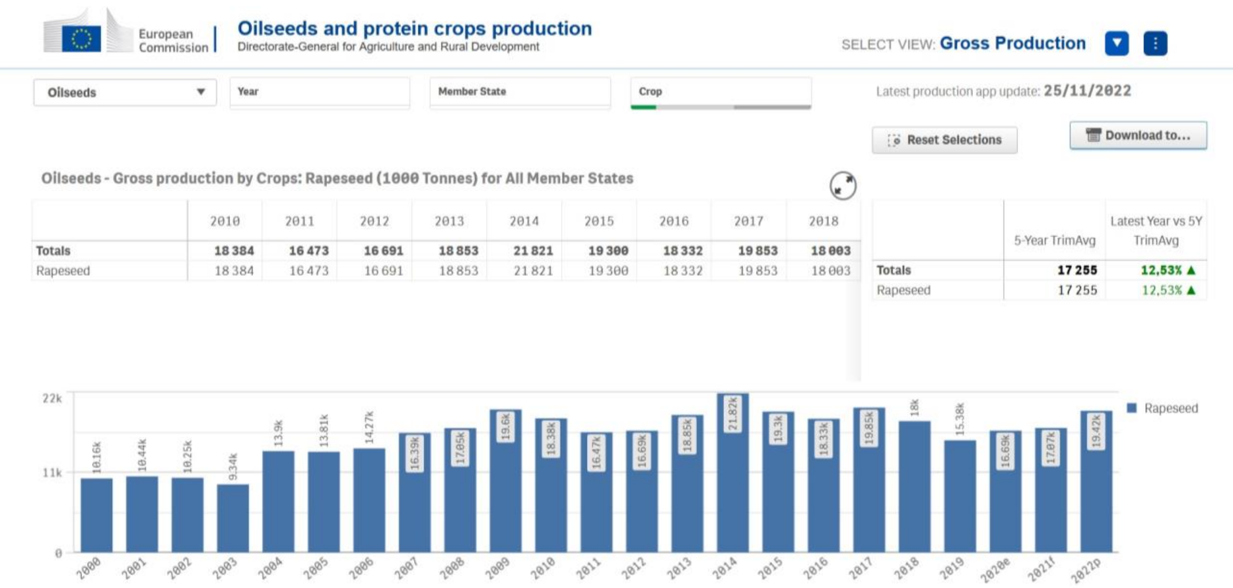
[2] (https://agridata.ec.europa.eu/extensions/DashboardCereals/OilseedProduction.html)

practices that can transform marginal land into an optimal soil condition or incorrect management can degrade prime land into marginal land.



	2010	2011	2012	2013	2014	2015	2016	2017	2018
Totals	18 384	16 473	16 691	18 853	21 821	19 300	18 332	19 853	18 003
Rapeseed	18 384	16 473	16 691	18 853	21 821	19 300	18 332	19 853	18 003

	5-Year TrimAvg	Latest Year vs 5Y TrimAvg
Totals	17 255	12,53% ▲
Rapeseed	17 255	12,53% ▲

Figure 4 Oilseed and protein crops production

Eurostat report the total area and gross production in (tonnes) for the main oilseed crop cultivated in the EU (Figure 4).

Table 2 Metadata table describe the metadata of the three Scenarios: i)CAMBAR CORINE 211 (croplands); ii) CAMBAR CORINE 241 Annual crops associated with permanent crops, 242 Complex cultivation patterns, 243 Land principally occupied by agriculture, with significant areas of natural vegetation: iii) CAMBAR CORINE 211 Cropland, 241 Annual crops associated with permanent crops, 242 Complex cultivation patterns, 243 Land principally occupied by agriculture, with significant areas of natural vegetation.

Field	Description
Metadata compiler	Calogero Schillaci
Identification	Unique identification of the dataset, DOI soon available
Context of dataset	Bio4A EU-Project,
Title1	211414243_CAMBAR_esdac.tif
Title2	2414243_CAMBAR_esdac.tif
Title3	211_CAMBAR_esdac.tif
Short description	The Camelina yield in current rainfed agricultural land CLC 211-2018; is part of the BIO4A project deliverables. It is used to estimate the potential amount of feedstock that can be produced in the selected Koeppen bioclimates (Bwk, Bsh, Bsk, Csa, Csb, Cfa) and promoting sustainable use of land which is embedded in the European Commission's Priorities under the European Green Deal and the Renewable Energy Directive. This conservative scenario is considering the potential cultivation of Camelina in rotation with Barley in agricultural land that can benefit from crop diversification.

Long description	The Camelina yield in current rainfed agricultural land CLC 211-2018; is part of the BIO4A project deliverables. It is used to estimate the potential amount of feedstock that can be produced in the selected Köppen bioclimates (Bwk, Bsh, Bsk, Csa, Csb, Cfa) and promoting sustainable use of land which is embedded in the European Commission's Priorities under the European Green Deal and the Renewable Energy Directive. This conservative scenario is considering the potential cultivation of Camelina in rotation with Barley in agricultural land that can benefit from crop diversification.
Format	Geotiff
	Features in the dataset (e.g. points, lines, polygons); free text
Spatial resolution-Unit of Measurement	Resolution (grid; e.g. 500 x 500m); t ha^{-1}
File / service Location	tbc
Geographic extent	Geographical coverage (e.g. EU, Italy, Spain, France, Portugal, Greece, Croatia)
Temporal extent	Reference period for the data (e.g. 2000-2020)
Reference system	Spatial Projection information, Lambert Azimuthal Equal Area
Status (*)	Deliverable accepted
Access constraints (*)	Publicly available after registration; for any use
Usage constraints (*)	No legal use constraints; only citation of source required
Keywords for dataset	Camelina-Barley rotation; Feedstock; Mediterranean; Yield; Modelling
Contact for dataset	Distributor: European Commission Joint Research Centre; ec-esdac@ec.europa.eu, owner Bio4A H2020 consortium, pointOfContact: calogero.schillaci@ec.europa.eu, tommaso.barsali@record.com)
Sources	Details can be found in the Deliverable 2.7 and 4.4. The model estimates the yields year by year averaged in the 20 years period. This provides an indication of the stable economically feasible regions (regions with an yield > 1.4 t ha-1), which occurs when agricultural area cultivated with Camelina in rotation with Barley has produced in average 1.4 t ha-1. The map builds on data from: • Köppen climates (Beck et al., 2018) • MARS Gridded Agro-Meteorological Data in Europe (https://agri4cast.jrc.ec.europa.eu/dataportal/) • Digital elevation model (SRTM) for derivation of SLOPE and ASPECT (open topography) LUCAS soil organic carbon and texture maps (Ballabio et al., 2016)
Lineage	Data used for the modelling procedure are all public and referenced with peer-review publications, for details please refer to Deliverable 2.7 and 4.4
Language	English
Citation	Deliverable 2.7 and 4.4
Maintenenance frequency (*)	Not applicable
Modification date	31-01-2023

4.1 Scenario current rainfed cropland based on CLC 2018 class 211

Figure 5 reports the scenario obtained on CLC classes 211.The modelling procedure is described in Deliverable D2.7 [Assessment of potential for drought-resistant oil crop in marginal land of Southern Europe and abroad].

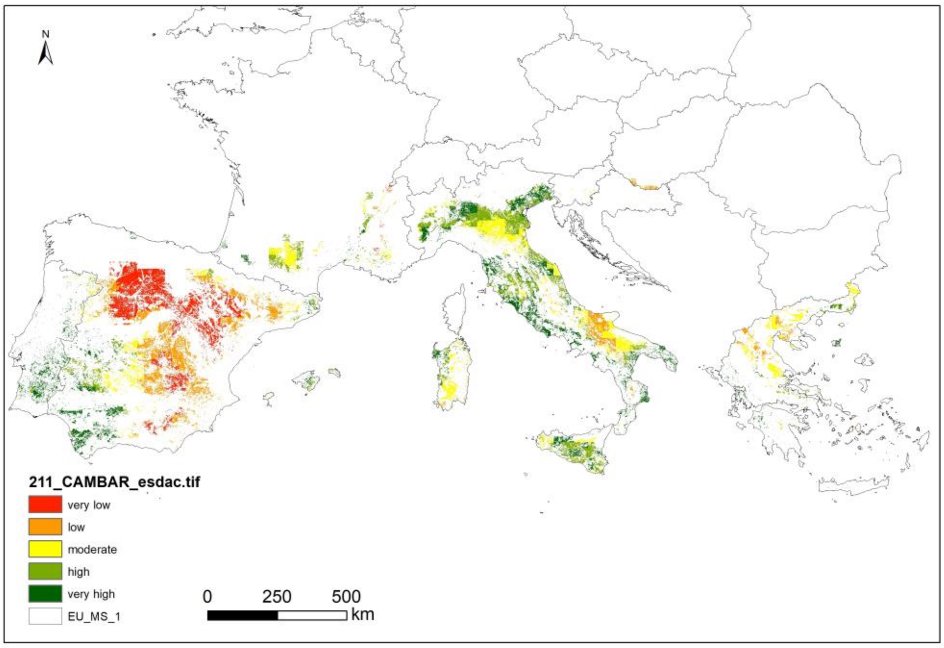


Figure 5 Scenario current rainfed cropland based on CLC 2018 class 211

4.2 Scenario current mixed land cover based on CLC 2018 classes 241,242,243

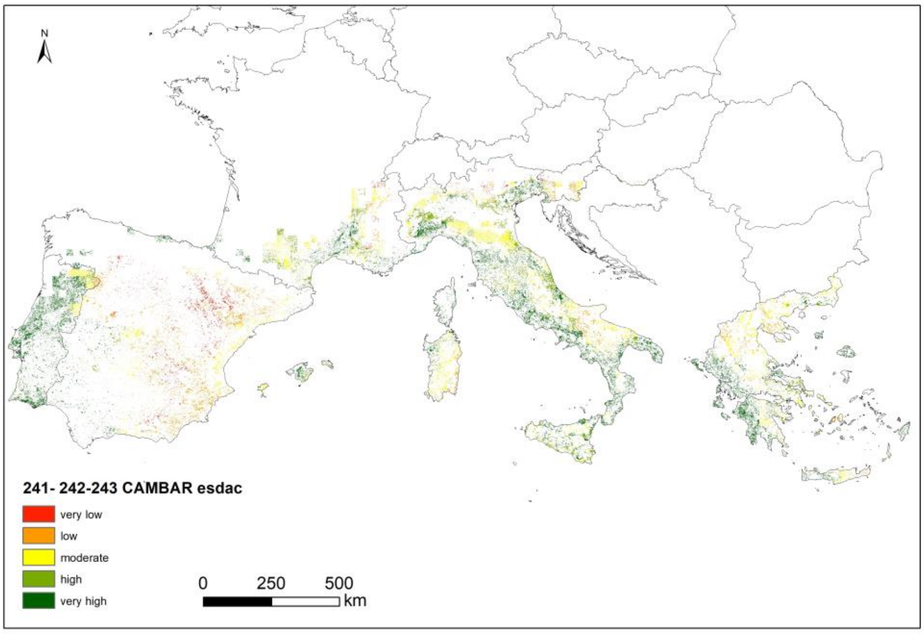


Figure 6 Scenario showing current mixed land cover based on CLC 2018 classes 241,242,243

Figure 6 reports the scenario obtained on CLC classes 241,242,243. The modelling procedure is described in Deliverable D2.7 [Assessment of potential for drought-resistant oil crop in marginal land of Southern Europe and abroad].

4.3 Scenario current rainfed cropland and mixed land cover classes 211,241,242,243

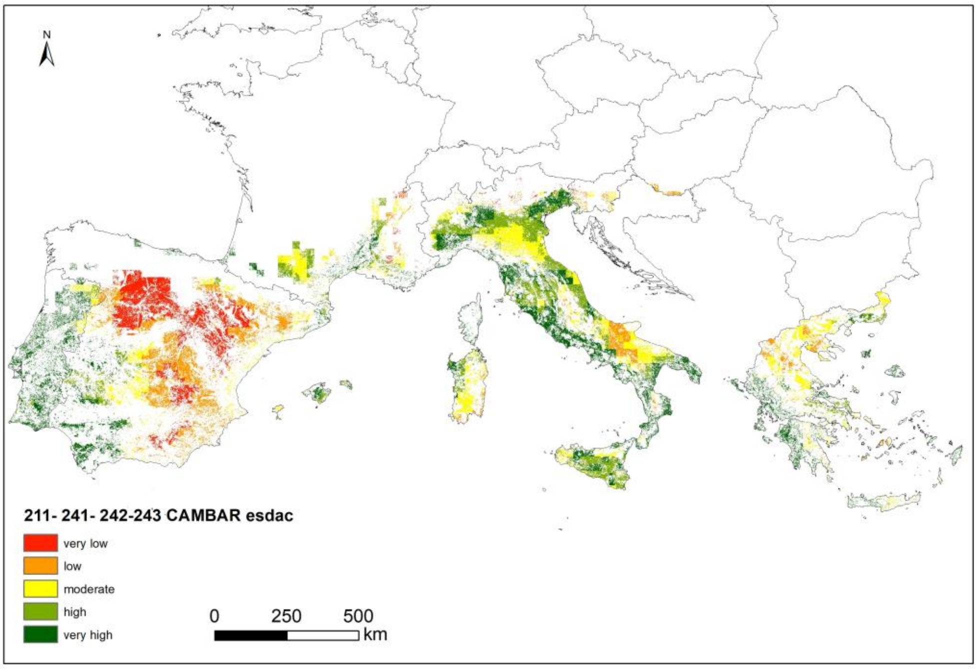


Figure 7 Scenario current rainfed cropland and mixed land cover classes 211,241,242,243

Figure 7 reports the scenario obtained on CLC classes 211, 241, 242, 243. The modelling procedures is described in Deliverable D2.7 [Assessment of potential for drought-resistant oil crop in marginal land of Southern Europe and abroad].

5. The Environmental sustainability of feedstock potential production on marginal land

The Environmental sustainability of feedstock production was assessed through the application of a Convergence of Evidences (CoE) approach that has been applied to the main soil and plant threats. For the details about the products used, a reference after the indicator proposed is provided after the indicator in the following list.

- **Soil Erosion** (Panagos et al., 2015)
- **Soil Compaction** (Gergely Tóth, Luca Montanarella, 2015)
- **Nitrogen inputs** (de Vries et al., 2021)
- **Soil biodiversity** (Orgiazzi et al., 2016)
- **Aridity index** (Zomer et al., 2022)

This set of environmental and soil related indicators have been collected in available repositories as spatial explicit datasets published along a pe-review publication. Their environmental sustainability and suitable threshold published reference classifies their impact in environmental terms have been taken into account. The CoE is a research strategy that involves collecting data from multiple sources and methods to address a research question or hypotheses. It involves collecting data from multiple research methods (e.g. surveys, interviews, experiments, archival analysis), multiple sources (e.g. primary and secondary sources), and multiple contexts (e.g. different countries, different times). This approach helps to increase the validity of the research findings, as it reduces the risk of bias or errors that can be introduced through relying on a single method or source.

The Aridity Index (AI) is a measure of the dryness of a climate. It is calculated by dividing the potential evaporation (ET0) of a region by its annual precipitation. The AI measures how much moisture is in the air compared to the amount of moisture that could theoretically evaporate from the region. The AI is used to classify climates into five general categories: hyperarid, arid, semi-arid, sub-humid, and humid. Hyperarid climates are those with the highest AI, typically over 0.5. These climates are found in the driest deserts and receive very little precipitation. The Sahara desert is an example of a hyperarid environment. Arid climates have an aridity index between 0.2 and 0.5. These climates are usually found in the subtropics and receive little precipitation. Examples of arid climates can be found in Mediterranean coastlines. Semi-arid climates have an aridity index between 0.05 and 0.2. These climates are found in the mid-latitudes and receive slightly more precipitation than arid climates. Parts of Central Spain and Italy are examples of semi-arid climates. Sub-humid environments have an aridity index between 0.02 and 0.05. These climates are found in the mid-latitudes and receive more precipitation than either arid or semi-arid climates. The aridity index is an essential measure of climate because it tells us how much water is available in a given area. It can be used to determine the types of plants that can be grown in an area, the types of fauna that can be supported, and the types of land uses that are possible. It can also be used to identify areas at risk of drought and water shortages.

Soil compaction (SC) is a process that changes the soil's physical structure, making it denser.. This process is important for many reasons, including decreasing crop yields, controlling erosion, and improving soil quality. Compaction affects soil permeability, fertility, drainage, and ability to hold water and air. It can also reduce the amount of organic matter and nutrients available to plants and animals. Mechanical, chemical, or biological processes can cause SC. Mechanical SC is caused by the weight of heavy machineries, such as tractors, combines, and other implements. Biological SC is caused by the activities of organisms, such as earthworms and roots, that break down soil particles and lower SC (Gambella et al., 2021). Compaction can affect heavily soils depending on the soil type and the intended use. In some cases, light SC can improve soil structure (e.g. rolling after harrowing) and increase seed adherence to soil by creating denser, more compact layer of soil with improved water-holding capacity.

Excessive SC can reduce soil fertility, water and air permeability, and water-holding capacity. There are several ways to reduce SC, including conservation tillage, crop rotation, and cover crops. Conservation tillage is a technique that minimizes soil disturbance, which reduces compaction. Crop rotation involves alternating between crops that require different amounts of SC and cover crops, which help protect the soil from compaction. In addition, soil can be aerated by incorporating organic matter and adding beneficial organisms, such as earthworms, to the soil. Soil compaction is a necessary process affecting soil's physical, chemical, and biological properties. There are several methods for reducing SC and improving soil quality, including conservation tillage, crop rotation, and cover crops. Proper management of land to avoid SC is essential for maintaining healthy soils and achieving optimal crop yields.

Soil biodiversity conservation is a crucial component of sustainable ecosystems.. Soil biodiversity plays a vital role in the functioning of ecosystems and is necessary for sustainable agriculture, food security, and ecosystem services. As the human population continues to expand, there is an increased demand for resources, leading to soil degradation and loss of biodiversity. It is, therefore important to protect and conserve soil biodiversity to maintain healthy and productive ecosystems (Orgiazzi et al., 2015).

Soil biodiversity can be conserved through several approaches. One of the most essential and effective strategies is establishing protected areas, such as national parks and nature reserves. These areas provide a refuge for some of the world's most threatened species and ensure that their habitats remain intact. Additionally, the implementation of agroecological practices, such as crop rotation and cover cropping, can help to promote soil fertility and conserve soil biodiversity. These practices can reduce the need for chemical fertilizers, herbicides, insecticides, and help to maintain nutrient cycling and soil structure. The use of local landraces of energy crops and the development of new drought-resistant varieties is also important for the conservation of soil biodiversity. Native species have evolved to thrive in the local environment and are better adapted to the climate and soil conditions than non-native species. Native species can also provide food and habitat for native wildlife, whereas non-native species can cause competition and displacement. Furthermore, the use of local landraces can help to preserve genetic diversity and promote resilience to disturbances such as climate change.

Finally, it is important to reduce soil disturbance and reduce the impacts of land-use changes. Soil tillage in high hillslopes can lead to soil erosion, declining soil fertility and degrading soil biodiversity. Land-use changes, such as intensive agriculture and soil sealing, can also lead to soil degradation and loss of biodiversity (Borrelli et al., 2016). By minimizing soil disturbance and land-use changes, we can help to conserve soil biodiversity. In conclusion, soil biodiversity conservation is essential for healthy and productive ecosystems. It is crucial to establish protected areas, implement agroecological practices, use native species, and reduce soil disturbance and land-use changes to protect and conserve soil biodiversity. By taking these steps, we can ensure that our soils remain healthy and productive for generations.

Soil erosion is a process that occurs when soil or sediment is removed from a particular area by several different forces, such as wind, water, and human activities. It is a significant cause of land degradation and soil loss and can have profound implications for agricultural productivity, food security, and the environment. A variety of factors, including overgrazing, over-cultivation, and deforestation, cause soil erosion. These activities can lead to soil destabilization, which releases large amounts of soil particles. Wind and water are the two main agents of soil erosion. Wind erodes soil by lifting and transporting particles away from their original location (Foerster et al., 2014; Gutiérrez et al., 2009; Panagos et al., 2015).

Meanwhile, water erosion can occur when rainwater or snowmelt washes away soil particles. In addition, human activities such as logging, mining, and urban development can also lead to soil erosion. The RUSLE, or Revised Universal Soil Loss Equation, is a tool used to predict the rate of soil erosion. It combines the effects of rainfall intensity, soil erodibility, slope length, slope gradient, land management practices, and cover or vegetative cover. This equation can be used to estimate the amount of soil loss that can occur in a given area over a specific period. The RUSLE can be used to help identify areas that are particularly vulnerable to soil erosion, as well as to help develop land management plans that can reduce soil erosion. It can also be used to evaluate soil conservation measures, such as specific land set up, terraces and contour ploughing, and to determine the most suitable vegetation types for a given area.

In conclusion, soil erosion is a severe problem that can significantly impact agricultural productivity and the environment. The RUSLE can help identify areas particularly vulnerable to soil erosion and develop land management plans that can reduce soil loss. It is essential to understand the causes and consequences of soil erosion and to use the RUSLE to develop strategies for managing and conserving soils.

Soil nitrogen is a vital nutrient for plant growth and productivity, and it is essential for a healthy and productive agricultural system. However, when there is an excessive input of nitrogen into the soil, it can lead to a range of environmental problems. Excess nitrogen inputs in the soil can lead to nutrient imbalances, resulting in poor plant growth and reduced yields. It can also lead to increased soil erosion and leaching of nutrients, resulting in water pollution and soil degradation. Excess nitrogen can also lead to increased atmospheric nitrogen, contributing to air pollution. Excessive nitrogen inputs can come from natural and human activities, such as agriculture and industrial processes. In agriculture, synthetic fertilizers are the primary source of nitrogen inputs. If fertilizers are often applied in excess, this leads to an accumulation of nitrogen in the soil.

Similarly, a high load of animal farming can be harmful to soil health. Managing nitrogen inputs is essential for sustainable agriculture and for preserving the environment. Nitrogen inputs should be carefully monitored, and fertilizer applications should be minimized. Agricultural practices, such as crop rotation and cover cropping, can help reduce nitrogen inputs and maintain a healthy balance of nutrients in the soil. Additionally, efforts to reduce air pollution, such as using renewable energy sources, can help reduce atmospheric nitrogen inputs.

In conclusion, excess nitrogen inputs can lead to various environmental problems, such as soil degradation and water pollution. Careful management of nitrogen inputs is essential for sustainable agriculture and for preserving the environment. By monitoring nitrogen inputs and reducing fertilizer applications, farmers can help ensure that the soil is healthy and productive.

5.1 Convergence of Evidences (CoE) approach

Because of the increasing pressures exerted on soil, crop productivity and soil biodiversity are under threat. To ensure agroecosystems resilience, it is necessary to capture early warnings of declining soil function, which are often measured through proxies (Net Primary Productivity decline, and cover changes and SOC stock) and categorize the already degraded land to track eventual improvements. The selected soil and environmental indicators takes into account the different components of soil's physical-chemical properties and its capacity to host micro and macrofauna. The European Soil Observatory dashboard is an actual example on how CoE, including all the LD proxies and derived indicators are combined to assess the potential state of soil health. To assess the environmental sustainability (ES) of the feedstock production in the study area, we used the CoE approach, with indicators t derived from evidence synthesis literature. Through an additive model, this approach allowed us to preliminarily evaluate the spatial patterns of soil degradation and, as a result, the environmental sustainability that feedstock cultivation for energy production will exert. The land cover analyzed is CORINE agricultural soils (code 2) which are the most exposed to pressure. Additionally, as a measurement of environmental potential for crop cultivation, the aridity index (AI) provides insights into the study area's potential sustainability for the cultivation of drought-tolerant Camelina variety and other similar crops.

Table 3 (Soil and environmental indicators and proposed Thresholds)

Scores for class	**Soil Erosion**	**Soil compaction Mg m-3 (taken as a proxy from Soil Bulk Density from SoilGrid 0-30 cm)**	**Nitrogen inputs kg ha-1 yr-1**	**Soil biodiversity (Potential threat to biological functions)**	**Aridity index AI ET0Annual V3 Robert J. Zomer, Jianchu Xu & Antonio Trabucco 2022**
5	<0.5	<1.3	<50	High	>0.65
4	0.5-1	1.3-1.4	50-80	Moderate -high	0.5–0.65
3	1-3	1.4-1.5	80-120	Moderate	0.2–0.5
2	3-5	1.5-1.5	120-150	Low Moderate	0.03–0.2
1	5-10	>1.6	>150	Low	<0.03

Table 4 (Environmental sustainability scores)

Environmental sustainability (ES) Classes related to scores
Very high (20-25)
High (15-20)
Moderate (10-15)
Low (5-10)
Very low (1-5)

Table 5 (CAMBAR predicted Camelina yield 2000-2020 reclassified in 5 classes)

CAMBAR predicted Camelina Yield
Very high (>2500 kg ha^{-1})
High (2000-2500 kg ha^{-1})
Moderate (1500-2000 kg ha^{-1})
Low (750-1500 kg ha^{-1})
Very low (<750 kg ha^{-1})

5.1 Results

Each indicator is reclassified in potential risk classes of ES (Figure 8), to understand the significance of these results, modelled yield and environmental sustainability have been reclassified using the Likert scale (1=low, 2=moderate, 3=adequate, 4=high and 5=very high) as it was adopted in (Pe'er et al., 2019).

The higher the number of cases with a potential increased risk of degradation, the lower the environmental sustainability very few spots report in northern Italy and southern Spain low ES, the dominant class is the moderate condition which is almost the half of the entire area under study. Mountainous regions resulted in good ES status, but generally, they are not so suitable for cropping.

Figure 8 shows the overlay of the CAMBAR predicted yield reclassified in 5 classes and the ES.

This approach may be used in future research to assess local and global threats, identify areas of possible risk, and, subsequently, design appropriate strategies for monitoring and protecting soil biota. The ES rating assessed using soil-related variables and aridity index as the climatic significance of the range of moisture availability conditions showed that the sea-facing areas are more vulnerable and need the adoption of conservation agricultural practices, improved organic carbon management to ensure environmental sustainability for agroenergy production. Additional ES measures, such as the use of organic fertilizers and organic mulch, should be put in place to rehabilitate land use types, especially arable land, to prevent further soil degradation under those land use types.

By linking the ES, and the potential yield of the CAMBAR average predicted yield (2000-2020) we can draw additional conclusions:

- The CoE approach is able to collecting data from multiple sources and providing a comprehensive understanding of the land conditions.
- To avoid desertification as the process by which fertile land becomes increasingly arid and dry due to environmental changes (droughts) and anthropic pressures (deforestation, overgrazing), as a result, the land becomes more and more impervious and generally biodiversity decreases the adoption of crop diversification and the use of drought-resistant crops is strongly advisable.
- GIS land suitability analysis must be integrated in crop models to evaluate multiple factors, such as soil type, slope, elevation, land cover, climate, and other environmental considerations, to determine which areas of land are best suited for a given activity. This type of analysis can help decision makers identify areas that are most suitable for energy crop cultivation.

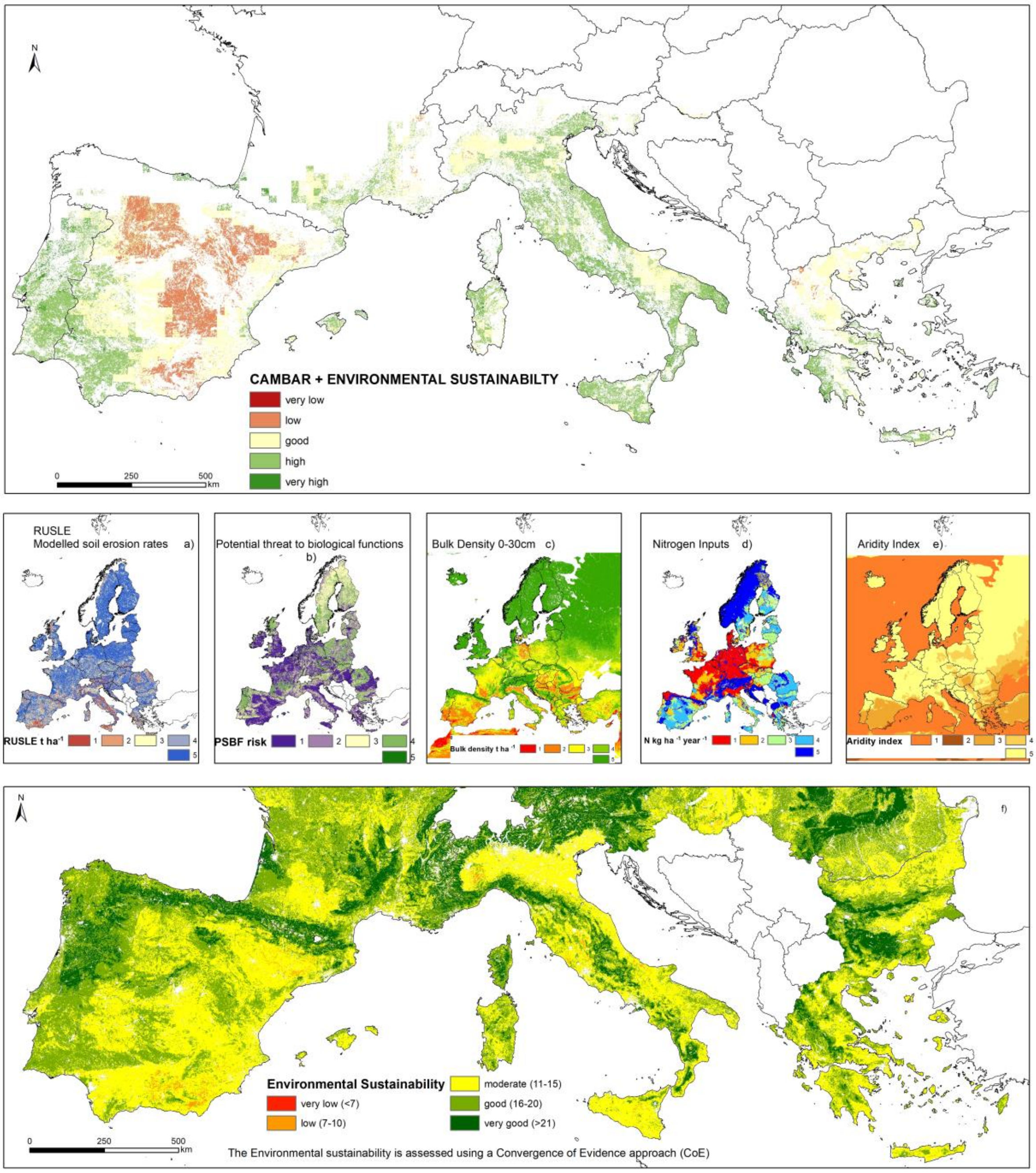


Figure 8. CoE of the CAMBAR ARMOSA average yield modeled (2000-2020) and the ES map obtained using five sub-indicators.

5 Conclusions

A crucial component contributing to the energy resilience of the European Union is land-use and the cultivation of feedstock for the provision of bioenergy; this can help reduce the emission of greenhouse gases and can support the agricultural sector. The spatial distribution of suitable land can affect both quantity and quality of the cropping systems as well as the ecosystems and their services. In addition, energy crop can help in recovering degraded lands if inserted in rotation, to cover the soil throughout the year, and mitigate climate change by storing more carbon and reducing GHG emissions. Land planning will require a special effort in order to improve cropping system resilience and avoid further degradation. Camelina is a vigorous crop that can tolerate a wide range of environmental conditions and can be grown on marginal land. It requires minimal inputs and can be successfully integrated into existing cropping systems. As a suggestion of previous modelling exercise (Deliverable 2.7), the Camelina can be grown in rotation with other cereal crops, and can be used as a companion crop to reduce weed pressure. In addition, camelina can serve as a source of organic matter to improve soil health. Camelina is a profitable crop in most Mediterranean land and offers a number of agronomic benefits. Its seed yield can reach the economic threshold to be valuable as cash crop, and its feedstock allowing producers to store their crop for extended periods. It also has a low input cost, making it a viable option for small-scale farmers. Camelina oil is in high demand and is sold as a food grade oil, an ingredient in animal feed, and a source of biofuel.

Camelina production is an excellent option for farmers looking to diversify their operations and increase their income. It is a hardy crop that can tolerate a wide range of environmental conditions and is relatively low maintenance, making it an ideal choice for small-scale farmers. With its high levels of omega-3 fatty acids and other nutritional components, camelina production offers a sustainable and renewable source of healthy food and fuel.

To better manage marginal land, flexible policy and practical solutions are needed to avoid land degradation and the adoption of measures such as nature-based socioeconomic development and policy development toward marginal land management. To preserve the socioeconomic importance of marginal areas, it is critical to develop rural areas that are economically or biophysically marginalised. Bioenergy crops by sustainable integration in cropland rotations is highly recommended.

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