GIS-BASED MODEL TO IDENTIFY MARGINAL SOILS FOR BIOENERGY PRODUCTION

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ABSTRACT: Energy crops are industrial species (woody, perennial and annual species, among others) that can generate biofuels, energy and bioproducts. Due to their tolerance, there is an interest to grow energy crops in marginal/contaminated/degraded soils, avoiding Indirect Land Use Change (ILUC) burdens. Therefore, this study aims at the development and use of Geographic Information System (GIS) tools to spatially relate land use selection and optimal species allocation, as an useful decision support systems (DSS), modelled to determine adequate marginal areas, inadequate for food and feed crops. ArcGIS software was used as a GIS tool, and parameters associated with areas considered to be marginal in mainland Portugal were identified. To identify marginal soils, it is necessary to know what type of criteria applies. It was considered the Regulation EU(1305)2013 - Annex III, that details all the criteria and the respective parameters, that a marginal soil should present being these, the base of this work. Considering all these criteria, a search in several databases was realized to collect the data that exist and how all these could be utilized to determine marginal soils in mainland Portugal. The maps obtained show that marginal soils in Portugal represent less than 10% of the territory.
Keywords: bioenergy, biofuel, biomass, geographic information system (GIS), marginal soils, model

1 INTRODUCTION

Bioenergy is a renewable and alternative energy, which is produced from the conversion of all organic material designated as biomass (including waste and energy crops) through chemical, biological, biochemical, and thermochemical processes. Energy crops are industrial species (woody, perennial and annual species [1,2], algae [3], among others) that can generate biofuels, energy and bioproducts being considered an alternative land use to promote the environmental, economic, and social sustainability of soils once it reduces the chance of conflicts caused by competition for food and feed, contributing positively to economic growth and for an additional revenue to landowners [4-6]. The different types of soils that presents interest to the energy crops in mainland Portugal are the marginal soils (salinity soils), contaminated soils (those that are polluted with other toxic elements and polymetallic agents) and degraded soils (lands eroded by natural factors such as climate change that cause a biological, physical and chemical change in its nature, generating soil desertification)[7-11], avoiding Indirect Land Use Change (ILUC) burdens.

To determine soils considered marginal it is necessary to use geospatial application systems being one of the most utilized the ArcGIS software from ESRI (Environmental Systems Research Institute) as a Geographic Information System (GIS) tool, through the introducing the data corresponding to several databases to identify parameters associated with areas considered to be marginal in mainland Portugal.

Generated data identify strategic areas of mainland Portugal where crops can be grown for energy purposes and at the same time, represent a possible solution to increase the sustainability of the marginal land and clean bioenergy/biofuel production. This work is not only expected to be relevant for researchers, scientists, and students, but will also serve as a baseline for technicians, decision-makers, and beneficiaries who are developing studies related to the geolocation of suitable areas for the implementation of cultures on an industrial scale such as biorefineries and biomass power plants, and on a smaller scale, such as farmers willing to invest in new agricultural species (in non-marginal soils) or in other market sectors such as the industrial one, based on the production, availability, and sale of feedstocks, namely, energy crops on marginal soils.

This study aims at the development and use of GIS tools to spatially relate land use selection and optimal species allocation, as a useful decision support systems (DSS) modelled to determine adequate marginal areas, inadequate for food and feed crops, for the implementation of selected energy crops in mainland Portugal.

2 METHODOLOGY

2.1 Baseline

To search what areas could be identified as marginal it is necessary to know what type of criteria should be considered to a marginal soil. The document created by the European Commission (EC) through Joint Research Centre (JRC) entitled "Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by specific constraints" that detail and describe the Regulation EU(1305)2013 - Annex III represent the baseline to establish all the criteria and the respective parameters, that a marginal soil should present [12]. The main criteria are excess soil moisture, dryness and low temperature, steep slope and lastly, the criteria connected to the poor chemical properties of the soil, unfavorable texture and stoniness, limited soil drainage and shallow rooting depth. This document established in a general and specific form the marginal criteria, therefore, all the areas that fulfill with one of these criteria are considered marginal.

Table I briefly presents all the criteria mentioned before and for each of these, the respective parameters considered marginal in the Regulation EU(1305)2013 - Annex III. Table I is presented below:

Table I: Criteria and thresholds from Regulation EU (1305) 2013 [12].

Criterion	Definition	Threshold Regulation EU (1305) 2013 – Annex III
Climate		
Low Temperature	Length of Growing Period	≤ 180 days
	Thermal-time sum (degree-days)	≤1500 degree-days
Dryness	Precipitation/ Potential Evapo-Transpiration	≤ 0.5
Climate and soil		
Excess Soil Moisture	Number of days at or above field capacity	≥ 230 days
Soil		
Limited Soil Drainage	Areas which are water logged for a significant duration of the year	Wet 80cm > 6 months, or 40cm > 11 months Poorly or very poorly drained Gleyic colour pattern within 40cm
Unfavourable Texture and Stoniness	Relative abundance of clay, silt, sand, organic matter (weight %) and coarse material (volumetric %) fractions	≥ 15% of topsoil volume is coarse material, rock outcrop, boulder (▲)
		Texture class in half or more (cumulatively) of the 100 cm soil surface is sand, loamy sand (■)
		Topsoil texture class is heavy clay (≥ 60% clay)
		Organic soil (organic matter ≥ 30%) of at least 40cm (▼)
		Topsoil contains 30% or more clay and there are vertic properties within 100cm of the soil surface (♦)
Shallow Rooting Depth	Depth (cm) from soil surface to coherent hard rock or hard pan	Rooting depth ≤ 30cm (►)
Poor Chemical Properties	Presence of salts, exchangeable sodium, excessive acidity	Salinity ≥ 4 dS/m in topsoil
		Sodicity ≥ 6 ESP in half or more of the 100 cm surface layer
		Soil Acidity Topsoil pH (H_20) ≤ 5 (●)
Terrain		
Steep Slope	Change of elevation with respect to planimetric distance (%)	Slope ≥ 15% (◄)

2.2 Data sources

Several databases from official websites of Portuguese, European and World Institutions and Projects were consulted to know in which of these are there or not the parameters that should be fulfilled for each criterion associated with areas considered to be marginal, such as Portuguese platforms and respective institutions like Sistema Nacional de Informação Geográfica (SNIG) from Direção-Geral do Território (DGT) [13], Geocatalogo from Instituto da Conservação da Natureza e das Florestas (ICNF) [14], Direção-Geral de Agricultura e Desenvolvimento Rural (DGADR) [15], Infosolo from Instituto Nacional de Investigação Agrária e Veterinária (INIAV) [16], EPIC WebGIS from LEAF - Linking Landscape, Environment, Agriculture and Food from Instituto Superior de Agronomia – Universidade de Lisboa (ISA-UL) [17] among others like Agência Portuguesa do Ambiente (APA) and Empresa de Desenvolvimento Mineiro (EDM). One of the main European platforms at soil level is the European Soil Data Centre (ESDAC) JRC [18] being other institutions or Projects the European Environment Agency (EEA), BIOPLAT-EU Project, Magic – Marginal Lands for Growing Industrial Crops Project, Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), among others. Other important institutions are the World Bank Group and Energy Sector Management Assistance Program (ESMAP).

The only data that were collected in several consulted databases are those highlighted in gold background in Table I. These data sources are presented below in Fig. 1.

Figure 1: Data source where the maps searched were collected

2.3 Collected and used data in each simulation

Considering the data sources specified in the point 2.2, the only data that were collected in accordance with the criteria highlighted in gold background in Table I were those related to coarse material, sand, organic content, clay, depth available to roots, pH in water (H_2O) and slope. As several types of maps to the same criterion being from same source and from different years were collected, several simulations using different data were created.

Before creating each simulation, it is necessary to carry out several tasks in the ArcMAP program of the ArcGIS software in order to perform a previous treatment on each map based on the origin (European or Portuguese) and the properties of each data. The procedure applied is explained following:

- All data collected in ArcMAP were introduced.
- It was verified which type of data represented each case, all of which were Raster type; therefore, conversion to vector format was necessary. This option is a matter of preference because many experts use data in raster format.
- After converting to vector format, the Coordinate System Projection should be checked. In case you want to use the data for a specific country, for example Portugal, you should find out which one should be applied, this being the ETRS89 and the transverse Mercator cartographic projection for mainland Portugal [19] and in the event that the projection of each data is different from the intended

one, it should be converted.

- If the data found are at the European level, as with all the maps found in the ESDAC, the selection data should only be carried out for the intended country or region. For example, if you want to have data only for mainland Portugal, should use the Official Administrative Charter of Portugal (CAOP) [20] performing a "Clip" (ArcGIS tool) between both maps, in order to obtain only the data for this territory.
- After each parameter is in the type of format, projection and spatial dimension that is desired, a selection should be made by attributes to obtain a layer with only the data that is applied to marginal areas, therefore, based on the limits established in the third column of Table I.
- In cases where criteria are specified only for topsoil, only maps that are identified in this soil zone will be used, as with coarse material and clay. For those where this is not specified, an average between the topsoil and subsoil maps should be determined, as with sand and organic matter, and this calculation must be carried out when the map is still in raster format.
- As there are two types of maps available for coarse material, clay (both topsoil) and organic matter, several map simulations can be carried out for each criterion highlighted in Table I, in order to use different maps in each simulation and then comparing each case with each other. However, a final map will always be obtained for each simulation. This final map should contain the compilation of all data selected for each criterion, therefore for coarse material, sand, organic carbon content, clay, depth available to roots, pH in water and slope.

It is important to specify that either protected natural reserves or occupied areas for human and natural species could not be included in the selection; therefore, these three types of areas were discarded from the created map in each simulation.

In this way, a map is obtained to each simulation that identifies the areas considered marginal to mainland Portugal. It should be remembered that an area that meets only one parameter will already be considered as land not suitable for food and feed and therefore, each final map is the compilation of all the maps.

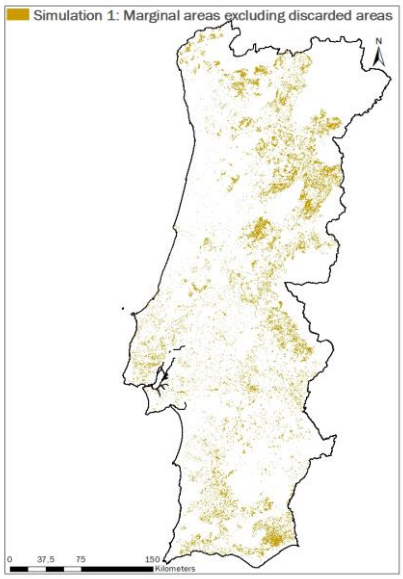
Table II which shows each type of map used in each simulation (according to the database to which it belongs and the year of the data) and the criteria selected in Table I, therefore, highlighted in gold background.

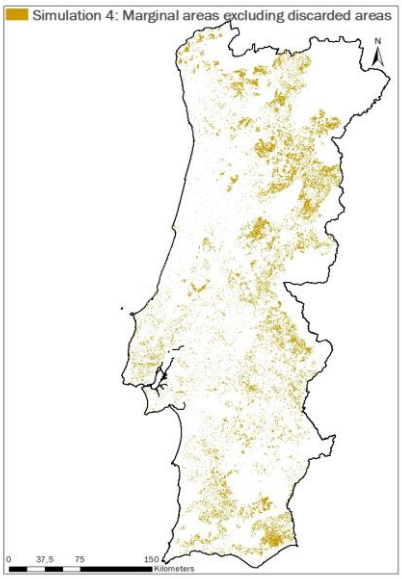
Table II: Collected and utilized data in each simulation with base in the criteria highlighted in gold background in table I

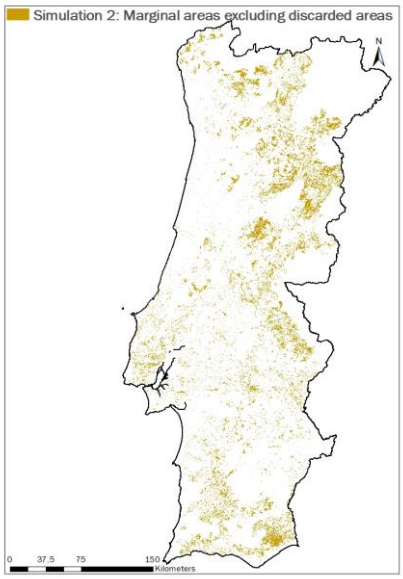
	Sim. 1	Sim. 2	Sim. 3	Sim. 4	Sim. 5
Union of all data selected to create a unique final map	Topsoil coarse fragments (ESDAC-JRC) 2013 (▲)		Coarse fragments (ESDAC-JRC) 2015 (▲)		-
	Sand content (ESDAC-JRC) 2013 (■)				Sand content map (Infosolo-INIAV) (■)
	Organic content (ESDAC-JRC) 2013 (▼)	SOC content (ESDAC-JRC) 2016 (▼)	Organic content (ESDAC-JRC) 2013 (▼)	SOC content (ESDAC-JRC) 2016 (▼)	-
	Topsoil clay content (ESDAC-JRC) 2013 (♦)		Clay (ESDAC-JRC) 2015 (♦)		Clay content map (Infosolo-INIAV) (♦)
	Depth available to roots (ESDAC-JRC) 2013 (►)				Soil thickness [LEAF-ISA (UL)] (►)
	pH in H_2O (ESDAC JRC) 2019 (●)				pH map (Infosolo-INIAV) (●)
	Slopes [LEAF-ISA (UL)] (◄)				
Discarded areas	Protected areas (ICNF) Portuguese National Agricultural Reserve (RAN) (DGADR) Criteria (artificialized land, agriculture, forest, agro-forestry systems, beaches, dunes, wetlands, among others) from Land Use and Land Cover (COS 2018) (DGT)				

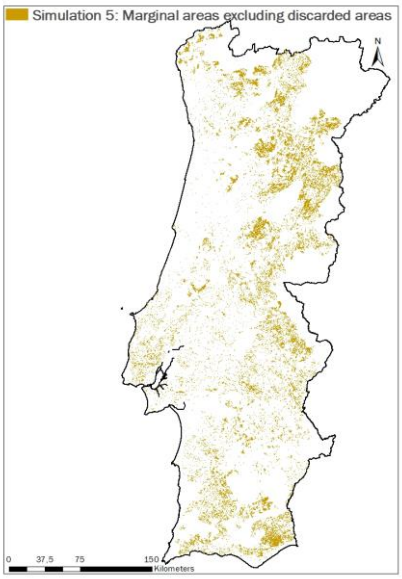
3 RESULTS

In Fig. 2, the final map created after each simulation, represents the marginal areas determined, therefore, unsuitable for food and feed production. However, it is important to safeguard the exclusion of the protected areas, of the Portuguese National Agricultural Reserve, and specific areas identified in the Land Use and Land Cover Map (COS 2018) that are not considered for the implementation of energy crops, therefore, these areas must not be considered as marginal areas, available for the cultivation of industrial crops.









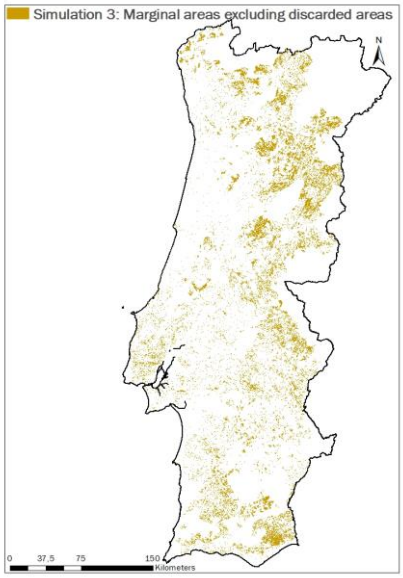


Figure 2: Marginal areas (excluding protected areas, Portuguese National Agricultural Reserve and some COS criteria - Discarded areas) of simulations 1-5 (check Table II for explanation of the simulations)

The obtained area in each simulation is mentioned in Table III where it is identified the area and the percentage of the Portuguese territory that is considered marginal.

Table III: Marginal soils areas and percentage of the Portuguese territory obtained in each simulation

	Area (kha)	Percentage (%)
Simulation 1	755.57	8.48
Simulation 2	755.56	8.48
Simulation 3	866.68	9.73
Simulation 4	866.04	9.72
Simulation 5	880.05	9.88

4 DISCUSSION

The EC has played a fundamental and preponderant role in the environmental, economic, and social sectors, with the objective of guaranteeing in the future the existence of agricultural food that can meet the needs of an ever-increasing human population, thus limiting the use of soils rich in carbon or suitable for agriculture in the cultivation of energy crops, therefore, non-food species. For these reasons, specific studies have emerged through projects created from institutions linked to the EC that assess soil properties, terrain conditions, climatic factors that can affect the different areas as well as their ecosystems. With base in this information, it is important emphasize the existence of a wide variety of data that allows evaluating on a national, regional, continental or world scale, specific criteria on different themes, an endless number of databases (how is mentioned in point 2.2 through the several data sources consulted) that provide public, unlimited, and open access information, with an ever-increasing number of topics covered.

As most of the maps were from the same database (ESDAC-JRC) and as within this, there were several datasets with maps for the same criteria but created in a different period time, it was necessary to assess how much the use of different maps could differ from each other, through the creation of several simulations in order to make a comparison between them, therefore, for the first four simulations, data from ESDAC-JRC (European database) were used in almost all cases. For the fifth simulation, all maps from Portuguese databases were utilized.

The several datasets belonging to the ESDAC-JRC were as follows:

- The dataset entitled "European Soil Database Derived data" that contain several parameters like coarse material, sand, organic and clay content (all these 4 parameters with topsoil and subsoil data) and depth available to roots [21];
- The dataset "Topsoil physical properties for Europe (based on LUCAS topsoil data)" with data about coarse fragments and clay (these 2 parameters with only topsoil data) [22];
- The dataset entitled "Maps of Soil Chemical properties at European scale based on LUCAS 2009/2012 topsoil data" that contain data about pH in H_2O [23];
- The dataset "Predicted distribution of SOC content in Europe (based on LUCAS, BioSoil and CZO) in the context of the EU-funded SoilTrEC project" with data about soil organic carbon (SOC) [24];
- The "EPIC WebGIS Portugal" contain the slope data [25] and soil thickness [26] and lastly;
- The dataset entitled "Infosolo" that contain several parameters like sand and clay content and lastly, pH [16].

Each dataset belongs to different years; therefore, some criteria may vary only in specific areas over time in the mainland Portugal territory. However, these differences are not considered significant since the area obtained in each simulation that does not differ too much from each other being this proven by the values specified in Table III even when using databases from different sources such as European ones (first four simulations) and Portuguese (fifth simulation).

Of the 5 simulations carried out, it will be considered as the final map of the marginal areas (755.57 kha), which corresponds to simulation 1 as it uses the most accurate data being almost all maps from the same year 2013 (except the pH map which is from 2019) and from the same ESDAC-JRC [except for the slope map which is from 2013 but from LEAF-ISA (UL)]. This final map shows that less than 9% of the mainland Portugal can be utilized to allocate energy crops for biofuels, energy and bioproducts production.

5 CONCLUSIONS

It can be affirmed and considered that the document created by the JRC is the basis for determining areas that, due to their poor conditions, cannot be considered for agriculture, therefore, marginal areas suitable for energy crops, unsuitable for food, and feed. With this document, it is important to study and determine areas that comply with each of the criteria specified in Table I, as well as a pairwise comparison between different criteria through an intersection between the areas to determine which of these comply with both factors. Unless data presented in this document are updated, the areas that are determined under these conditions will continue to be considered marginal.

Since this document is the basis, it can also be stated that there are many platforms and databases that allow the download of a wide range of data to complete and conclude studies related to soils or marginal lands.

The obtained area in each simulation does not differ too much from each other, being used maps from the same source (e.g. ESDAC-JRC) but from different years to the same criterion. The area of the three last simulations is very close; however, simulation 1 is considered the selected final map of marginal areas, as it uses the most accurate data being almost all from the same year 2013 and source (ESDAC-JRC).

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