Evaluation of the Potential of Biomass to Energy in Portugal - Conclusions from the CONVERTE Project

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S.1. Maps obtained from Direção Geral do Território (DGT)

S.1.1 Districts of the Official Administrative Charter of Portugal - CAOP

Official Administrative Charter of Portugal - CAOP identifies "the Official Administrative Limits at County, District/Island level. These limits also correspond to Nomenclature of Territorial Units for Statistics - NUTS I, NUTS II and NUTS III" [1].

The original shapefile, presented in the attribute table, the columns as follows: FID, Shape (Polygon), Dicofre, Freguesia (Parish), Concelho (Municipality), Distrito (District), among others. However, CAOP also makes available a document in excel format with the specification of NUTS I, II and III for Portugal. It was necessary to associate in the ArcMap the attribute table of the shapefile with this excel table, to evaluate all this data in a unique layer. As there is only interest in the mainland Portugal area, it was necessary to remove the data allocated to the island regions, namely, "Autonomous Region of the Azores" and "Autonomous Region of Madeira".

S.1.2 Land Use and Land Cover

Land Use and Land Cover - COS 2010 and COS 2015 are a land use and occupation thematic cartography map for mainland Portugal for the year 2010 and 2015, respectively, being the Direção-Geral do Território the entity responsible for its production. The COS 2010 and 2015 cartographic information are in vector format and divide the space into landscape units (polygons) that share the concepts of land use and occupation. Both COS have a minimum cartographic unit (UMC) of 1 ha, a minimum line distance of 20 m and the equivalent scale is 1:25,000. The nomenclature consists of a hierarchical land use/occupation class system with five levels, and has 225 (COS 2010) and 48 (COS 2015) classes at the most detailed level [2,3].

It was necessary to make the unification of all layers (flatter) in a unique map, because the data are available by regions, in order to represent all the parameters in a single layer. Once embedded in ArcMap, it was necessary to perform an attribute selection to create a map with the criteria of interest by culture, as detailed below:

- Cardoon, miscanthus and paulownia: concerning COS 2010, only six criteria were selected, namely "3.2.01.1 Natural herbaceous vegetation" that belongs to "Pastures", "3.2.2.01.1 Dense bushes", "3.2.2.02.1 Low dense bushes", "3.2.3.01.1 Dense sclerophyte vegetation", "3.2.3.02.1 Sclerophyte vegetation not very dense", "3.2.4.07.1 Other woody formations" all of these correspond to "Bushes" and "3.3.3.01.1 Vegetation sparse" that belongs to "Spaces discovered or with sparse vegetation", so these zones are considered marginal land, suitable for the implementation of energy crops. The same related criteria have been chosen from COS 2015 but there were sub categories not interesting for this study that cannot be eliminated for lack of detail

in this COS such as "Burnt areas not forest", "Firebreaks and/or fire breaker", "Beaches, dunes and sand" and "Sparse vegetation".

- Microalgae: the criterion that was chosen is "3.3.2.01.1 Nude rock" (COS 2010) that belongs to "Spaces discovered or with sparse vegetation", because it is appropriate for the installation of reactors that allow the mass production of several species of microalgae. This criterion was absent in COS2015, making impossible to perform this selection for microalgae.

- Cultivated agricultural/silvicultural species: the areas that presented cultivated species were selected (COS 2010). Therefore, all the parameters that correspond to the "Agriculture" (except "2.1.1.02 Greenhouses and nurseries"), the areas classified as "Forest" (without the criteria that include aspects related to burned areas) and all the lands that fit the "Agroforestry Systems (SAF)". Concerning COS2015, the criteria related with Agriculture, "Temporary crops of rainfed and irrigated", "Rice fields", "Vineyards", "Orchards", "Olive groves", "Temporary crops and/or pastures associated with permanent crops", "Cultural systems and complex parcel" and "Agriculture with natural and semi-natural spaces" were selected. Concerning Agroforestry Systems, "cork oak", "holm oak", "other oaks", "stone pine", "other species", "cork oak with holm oak" and "other mixed" were also selected. The forest areas of "cork oak", "holm oak", "other oaks", "chestnut", "eucalyptus", "invasive species", "other hardwood", "maritime pine", "stone pine" and "other resinous", were also nominated.

S.1.3 Corine Land Cover

The CLC 2012 was an "initiative of the European Environment Agency (EEA), together with the Member States, which aims to characterize land use/occupation in mainland Portugal in the year 2012. It is a thematic cartography produced from satellite imagery, available in vector format, with a Minimum Mapping Unit (UMC) of 25 hectare and a classification system with 3 hierarchical levels and 44 classes at the most disaggregated level" [4].

To create the maps relative to each species, the selection of attributes of interest was made, being the chosen criteria, those detailed below:

- Cardoon, miscanthus and paulownia: only four criteria were selected, namely "Natural herbaceous vegetation", "Bushes", "Sclerophyllic vegetation" and "Sparse vegetation", therefore, marginal areas suitable for energy crops.

- Microalgae: the factor identified as "Nude rock" was the only selected parameter.

- Agricultural/silvicultural species cultivated: the aspects denominated "Agriculture with natural and semi-natural spaces", "Rice fields", "Irrigated temporary crops", "Temporary rainfed crops", "Temporary crops and/or pastures associated with permanent crops", "Open forests, cuts and new plantations", "Hardwood forests", "Coniferous forests", "Mixed Forests", "Olive groves", "Orchards", "Agroforestry systems", "Cultural systems and complex parcel" and "Vineyards" were selected corresponding to the cultivated species that generate residues.

Figure S1 shows the 4 maps previously described namely the Districts of mainland Portugal, COS 2010, Corine Land Cover - CLC 2012 and COS 2015.
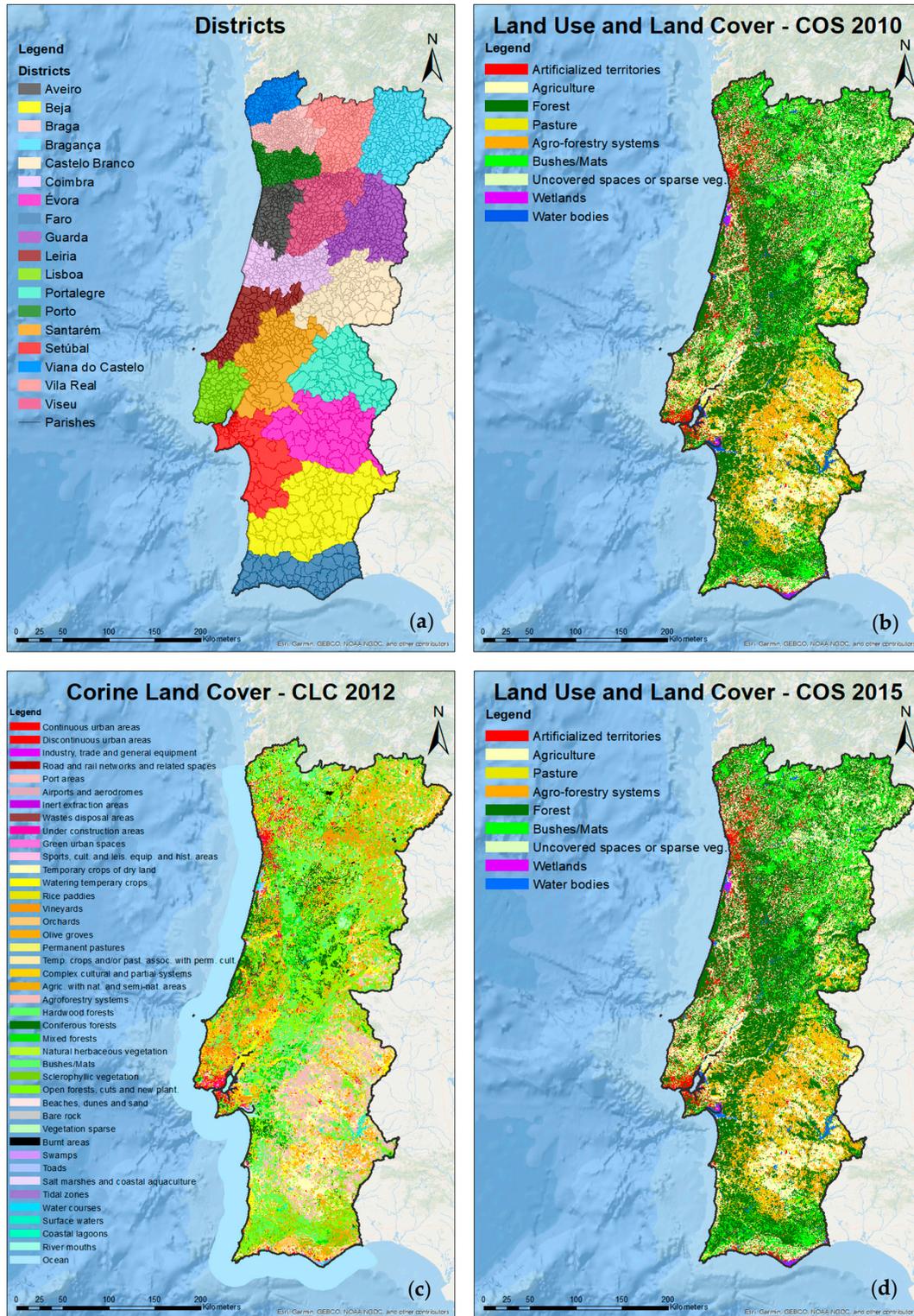
Figure S1. Maps obtained from the DGT website: (**a**) Districts of mainland Portugal from CAOP; (**b**) COS 2010; (**c**) CLC 2012; (**d**) COS 2015. (Adapted from [1,5–7]).

S.2. Maps consulted from Agência Portuguesa do Ambiente (APA)

S.2.1 Insolation

The insolation represents the "annual mean values (hours), period 1931-1960" [8].
The selected criteria for microalgae culture are specified below:

- Microalgae: should be adequate to high insolation conditions, such as more than 2500 hours per year. This map was just applied for this type of biomass, as no specific insolation conditions have been considered for the remaining species.

S.2.2 Temperature

"Daily average air temperature, annual mean values (degrees centigrade), period 1931-1960" [9]. The selected values for each culture are described as follows:

- Cardoon: although it can tolerate minimum temperatures down to −5 °C, it was considered the values "equal or superior to 7.5 °C".
- Miscanthus: it copes well with temperatures in the soil above to 8 °C, therefore, it was established a temperature value equal or superior to 8 °C.
- Paulownia: it supports either cold (−17 °C) or the heat (45 °C) very well.
- Microalgae: as the range of appropriate temperatures is from 10 °C to 40 °C, the parameters equal or superior to 10 °C were selected.

S.2.3 Precipitation

Precipitation represents the "total quantity, annual average values (mm), period 1931-1960" [10]. The assigned criteria for each culture are detailed below:

- Cardoon: although it can tolerate dry areas, its productivity decreases with a precipitation inferior to 450 mm/year. The closest specified value was 500 mm/year. All data above this value have been selected.
- Miscanthus and Paulownia: according to Table 1 and Table 2, average rainfall values equal or superior to 500 mm/year are required.

S.2.4 Frost

Frost is identified as "number of days in the year, annual average values (days), period 1941-1960" [11].
The established data for each crop are mentioned below:

- Cardoon: for the development of at least 4 leaves, temperatures higher than −5 °C are required. However, the data that correspond up to 60 days of frost was selected. The species may not tolerate higher frost, but those areas are not significant.
- Miscanthus: the same criteria previously described was applied. The selected data correspond to values up to 60 days of frost.
- Paulownia: it tolerates temperatures down to −17 °C., thus all the represented values in the map were considered.

Figure S2 shows the insolation, temperature, precipitation and frost for mainland Portugal.
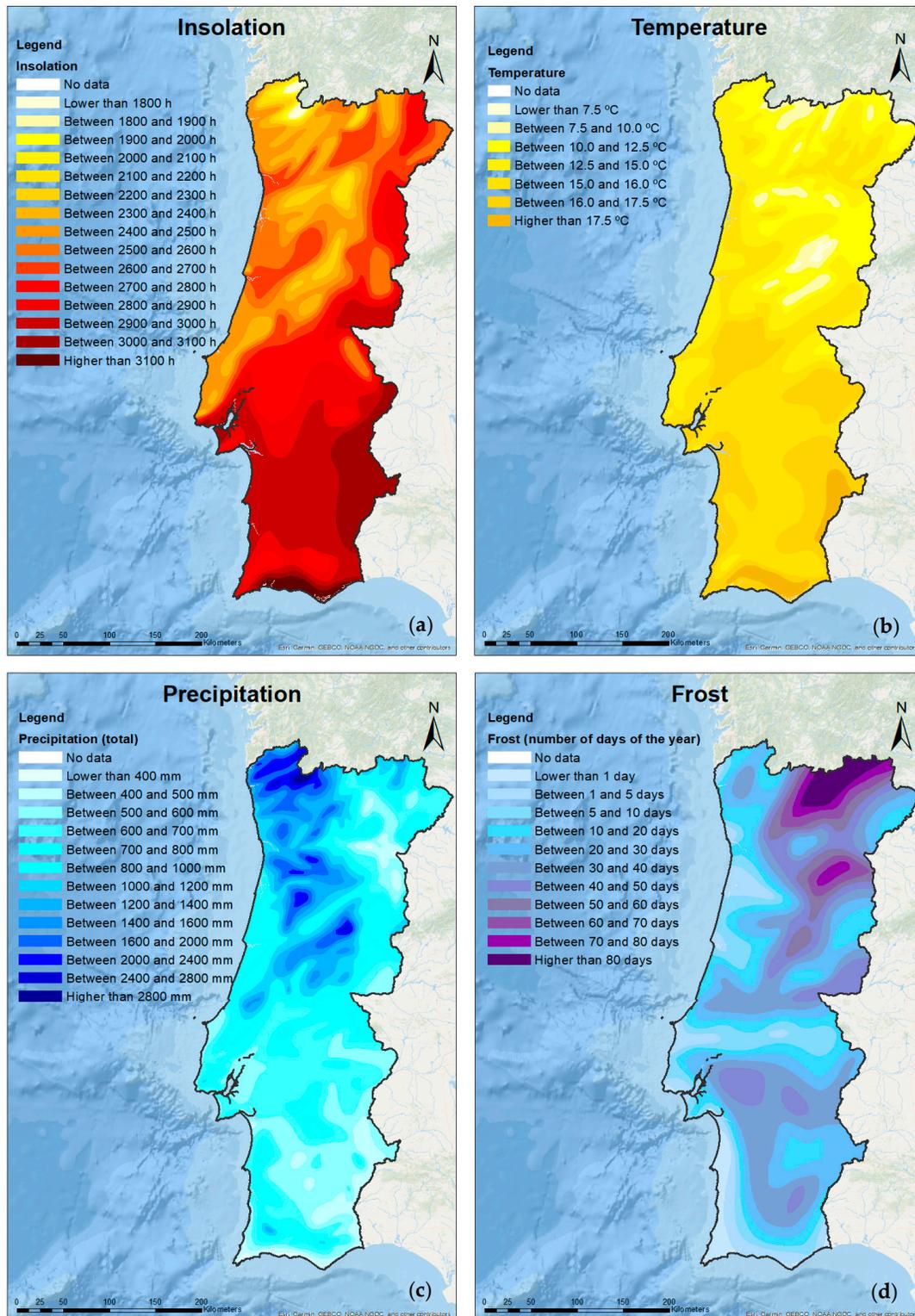
Figure S2. Maps presenting APA data (annual basis): (**a**) Insolation level measured in number of hours; (**b**) Average daily air temperature in °C; (**c**) Precipitation measured as the total amount (average values) in mm; (**d**) Map of frost in number of days. (Adapted from [8–11]).

S.2.5 Municipalities of mainland Portugal with CO$_2$ production in the energy and industrial sectors

The APA report entitled "Air Pollutant Emissions by County - 2015" was considered, which presents the "spatial distribution of air pollutant emissions under CLRTAP and UNFCCC greenhouse gas emissions at the county level, a work carried out in parallel with the international reporting exercises and is intended to overview of the geographical distribution of national emissions. APA annually produces the National Inventory Report (NIR) prepared under the UNFCCC and Kyoto Protocol, and the Informative Inventory Report (IIR) prepared under the CLRTAP and the National Emission Ceilings Directive" [12].

This report issued from APA dated of May 2017, consisted of a spreadsheet document with emission data by municipality and split for several sectors. Only those related to the energy and industrial sectors have been extracted as the largest CO_2 emitters [13].

It should be highlighted that only microalgae have been considered because only this type of biomass has the capability to bio sequestrate anthropogenic CO_2 previously dissolved in aqueous media.

S.2.6 Pollutant Release and Transfer Register–PRTR

"Decree-Law No. 127/2008 of July 21 (PRTR Diploma), ensures the conditions of execution and guarantee of compliance with the obligations arising for the Portuguese State of the European PRTR Regulation, of which stand out: Obligations of operators PRTR establishments (art. 5 and 6 of DL 127/2008); Obligations of the Agência Portuguesa do Ambiente - APA, IP (art. 2 of DL 127/2008); Obligations of the PRTR competent authorities (art. 2 and 3 of DL 127/2008); Fines and offenses (art. 8 of DL 127/2008) at national level, the reference document is the PRTR National Methodology" [14].

These data were incorporated only to verify specific points allocated to CO_2 production in the energy and industrial sectors, by large companies that, due to its size or scale, are located in the municipalities with greater CO_2 emissions, such as Sines. This map was only important for microalgae cultures, as detailed as follows:

- Microalgae: it is important to select locations with a high CO_2 emissions, from the energy and industrial sector. All the industrial subsectors with claimed higher GHG emissions (CO_2 into the atmosphere) have been considered as follows : "Steel"; "Biomass"; "Hydraulic lime"; "Non-hydraulic lime"; "Coal"; "Iron"; "Fuel oil"; "Natural gas"; "Kraft with bleaching"; "Unbleached Kraft"; No specific (in order to cover the identified as "Paste production", "Manufacture of refined petroleum products"; "Manufacture of industrial gases"; "Manufacture of cement and iron and steel industry and manufacture of ferro-alloys"); Other [to include "Paste production", "Manufacture of paper and paperboard (except corrugated paper)"; "Manufacture of paper and paper products for domestic and sanitary purposes"; "Manufacture of refined petroleum products"; "Manufacture of petroleum products from waste"; "Manufacture of cement and production of thermal origin electricity)"]; "Other - Biofuels"; "Other - Biodiesel"; "Other - Co-incineration"; "Other - Incineration of hazardous waste"; "Other - Fuel Treatment"; "Printing and writing paper"; "Paper, cardboard and packaging"; "Bleached sulphite"; "Tissue (paper mills)"; "Glass packaging"; "Domestic glass" and "Oils (Biodiesel Manufacturing Only)".

The selection of these criteria was made according to the areas of the industrial sector of which it is known that produce and emit greater CO_2 quantities.

Figure S3 depicts the 3 topics previously described: two maps with the Municipalities of mainland Portugal with CO_2 production in the energy (a) and industrial sector (b) and one map with the location of the identified companies in the Pollutant Release and Transfer Register - PRTR (c).
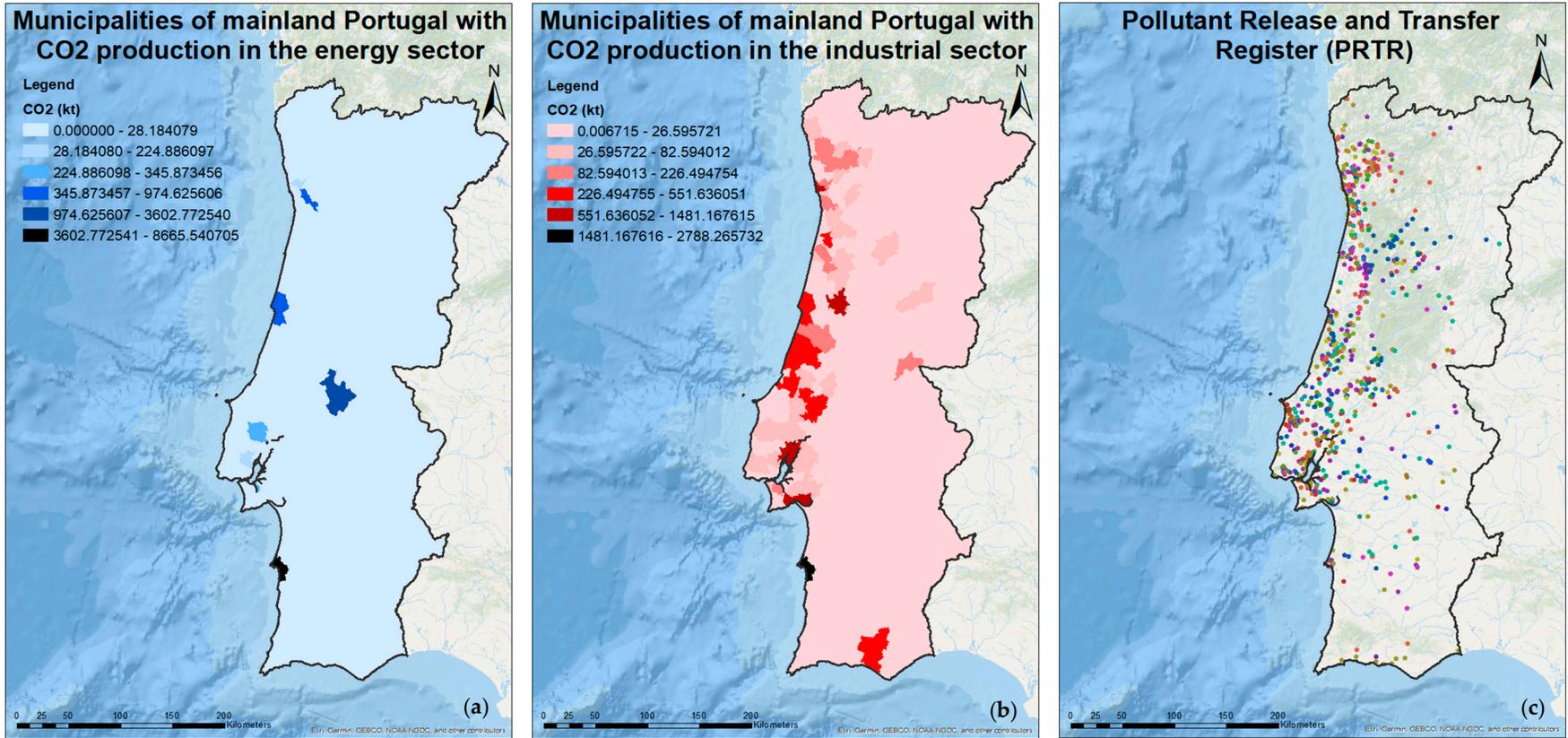
Figure S3. Consulted maps from APA (annual basis): (**a**) Municipalities *vs* the quantity produced CO_2 (emitted and released) in the energy sector; (**b**) Produced (emitted) CO_2 (kt) in the industrial sector *vs* Municipalities; (**c**) Location of the companies by subsector identified in the Pollutant Release and Transfer Register - PRTR, that represents the GHG emission sources in mainland Portugal. (Adapted from [1,13,14]).

S.3. Maps obtained from EPIC WebGIS platform (Instituto Superior de Agronomia, Universidade de Lisboa, ISA-UL)

S.3.1 Land steepness

"Represent the land steepness of the surface of the territory" [15].

The selected values in the land steepness map for each crop are specified below:

- Cardoon: the appropriate growth conditions of the crop are up to 15%, therefore, the slope has been considered from 0% up to 16%.
  As all the maps must be in the same vectorial format so that the intersection of all maps can be performed, the data that were in raster format were converted to the vectorial format (polygon representation).
  The previously described methodology was also applied to the cases described as follows:
- Miscanthus: the same described criteria for the cardoon were applied, therefore, slopes up to 16% were selected.
- Paulownia: as it is a forest type species, it can grow on slopes higher than those considered in herbaceous crops, being selected values up to 25%.
- Microalgae: land slope doesn't impose any limitation for the development of microalgae mass cultures. Slopes higher than 25% have been selected.

S.3.2 Soil texture

The soil texture identified "the particulates with a diameter less than 2 mm, called fine earth, responsible for influencing decisively important physical and chemical properties of soils, including structure, porosity, cation exchange capacity, buffer power etc." [16].

The soil texture map identified the criteria designated as:

- Fine: less than 18% of clay and more than 65% of sand.
- Median: less than 35% of clay and more than 15% of sand; or more than 18% of clay if the sand content exceeds 65%.
- Coarse: more than 35% clay, or less than 35% clay and less than 15% sand.
- Soil absence.

It was necessary to apply the conversion from raster to vectorial format, described in the land steepness map, being the selected soil texture criteria for each crop identified as follows:

- Cardoon: as it grows better in sandy-loam soils, and parameters corresponding to "fine" and "median" were selected.
- Miscanthus: suitable for sandy-loam soils with 10% of clay, and it was decided to choose the criteria "coarse".
- Paulownia: the same detailed criteria for cardoon was applied for this species, therefore, "fine" and "median".

S.3.3 Soil pH

The map relative to the soil pH identified "the acidity or alkalinity of the soil, a variable that affects the chemical, biological and indirectly physical properties of soil. Soil pH influences the availability of different elements absorption by plant roots, both as nutrients, toxic elements as well as the activity of soil microorganisms." [17].

The assigned data to each culture are described below:

- Cardoon: the soil must present a pH higher than 6 to guarantee the development of the species.
- Miscanthus: it was chosen the optimum pH values (5.5 to 7.5).

49　　• 　　Paulownia: it was chosen the suitable pH values (5.5 to 8).

50　　*S.3.4 Soil thickness*

51　　　　"Effective soil thickness is conditional on fertility and usable water storage capacity,
52　　allowing the determination to a large extent, soil suitability for the growth of certain species or
53　　group of species" [18].
54　　　　The selected values of soil thickness per crop are specified below:

55　　• 　　Cardoon: requires light and very deep soils that can hold the water to a depth up to 3 m. All
56　　　　the parameters up to 100 cm were selected, only excluding areas with soil absence.
57　　• 　　Miscanthus: requires soils with high capacity of water retention. All parameters "up to 30
58　　　　cm" have been selected.
59　　• 　　Paulownia: requires soils with good drainage, with water table in between 2 and 5 m. The
60　　　　same criterion applied to cardoon, namely, soils "up to 100 cm" excluding areas with absence
61　　　　of the soil, was selected.

62　　　　Figure S4 depicts the criteria previously described (land steepness, soil texture, pH and
63　　thickness).

64
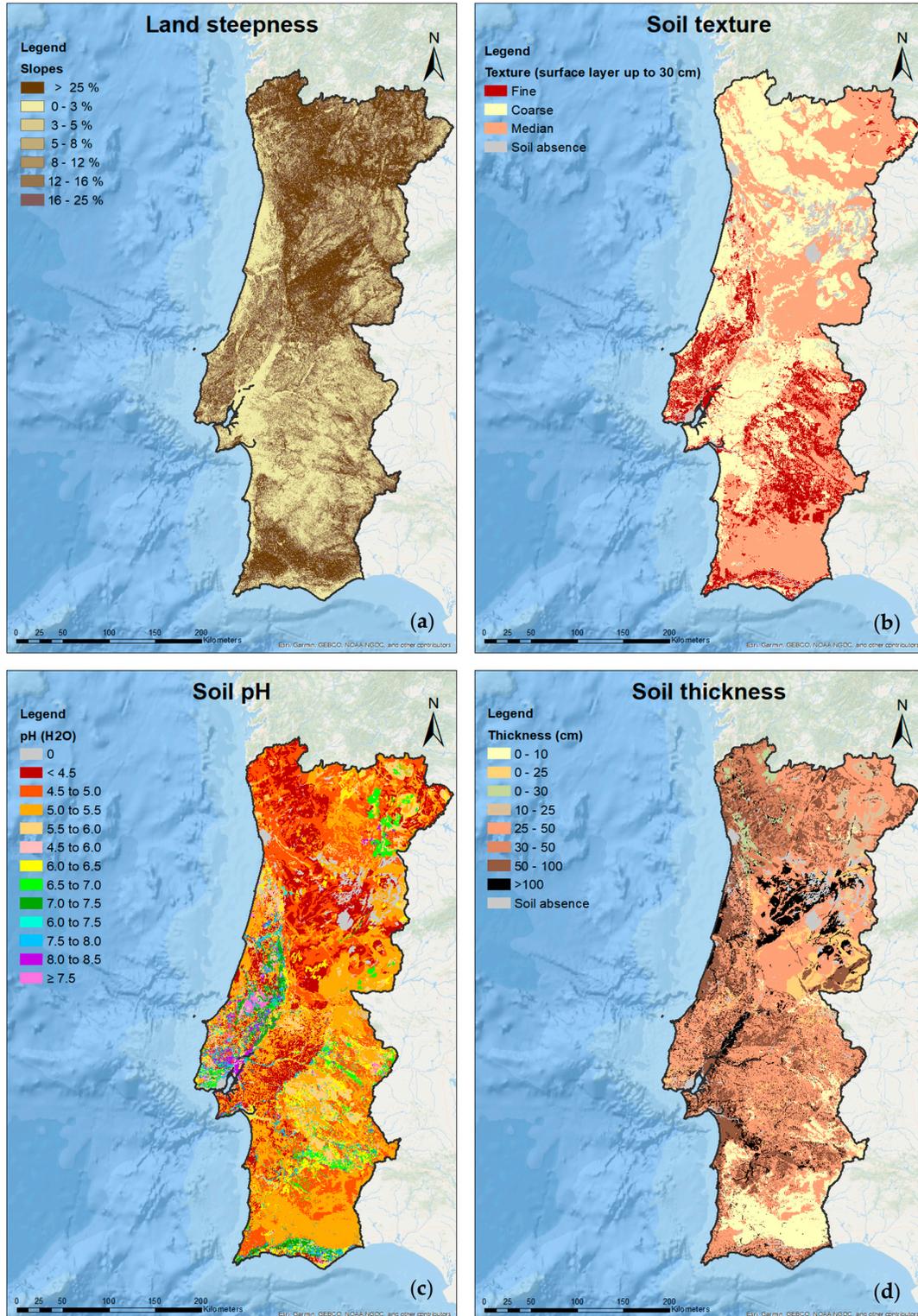
Figure S4. Maps obtained from EPIC WebGIS platform (ISA-UL): (**a**) Land steepness map measured in %; (**b**) Soil texture represented as the surface layer up to 30 cm; (**c**) Soil pH map from soils considered high acid up to very alkaline; (**d**) Soil thickness in cm. (Adapted from [15–18]).

S.3.5 Presence of physical obstacles

69　　　The presence of physical obstacles "is a feature that prevents, hinders or burdens the free
70　movement of machinery and livestock and limits the size of cultivated plots. Walls or terraces
71　built by man, which very significantly alter the surface of the slopes, increase the potential of the
72　land, substantially reducing the risk of erosion, allowing the irrigation in specific conditions and
73　the use of cultures with more or less deep rooting such as fruit trees and vines" [19].
74　　　The Presence of physical obstacles map detailed the next represented data:

75　•　　P—stony phase: soils that present high amounts of rude elements, of superior diameter to 2
76　　　　mm, with significant limitations for agricultural and forestry use.
77　•　　P T3—narrow and rocky terraces, T2—medium wide terraces and T3—narrow terraces:
78　　　　man-made terraces, limit the size of the fields for cultivation, hindering accessibility and
79　　　　crop management, especially the use of machinery.
80　•　　R2—rock outcrops exceeding 25–40% of the area and R3—rock outcrops exceeding 50–70%
81　　　　of the area: with significant limitations for agricultural and forestry use.
82　　　　To create the microalgae map, it was necessary to convert from the raster format to the
83　　　　vectorial format, described in the land steepness map, being the selected criteria as follows:
84　•　　Cardoon, miscanthus and paulownia: this map was not considered for these crops because
85　　　　it would limit the obtained area. For this reason, it was only considered for microalgae
86　　　　cultures.
87　•　　Microalgae: as the microalgae reactors can be installed in areas with the absence of the soil
88　　　　or in rocky areas (areas not suitable for the remaining crops), the criteria that correspond to
89　　　　"P—stony phase", "R2—rock outcrops exceeding 25–40% of the area" and "R3—rock
90　　　　outcrops exceeding 50–70% of the area" have been selected.

91　*S.3.6 Ecological Soil Value*

92　　　"Soil is a resource that supports all terrestrial ecosystems and is the basis for most food
93　production. The classification of the ecological value of soil is based on its intrinsic characteristics
94　and indicates a scale of relative importance of soils in any region of the Portuguese mainland,
95　including their productive and ecological potential" [20].
96　　　The identified data for each culture are specified below:

97　•　　Cardoon, miscanthus and paulownia: only the values that corresponded to the "reduced
98　　　　(E.V 2)" and "very reduced (E.V 1)" have been selected, due to the fact that these areas with
99　　　　a lower Ecological Value are inadequate for agriculture and suitable for energy crops.

100　*S.3.7 Current Permeability*

101　　　This map represent the "qualitative assessment of water infiltration capacity of the soil,
102　considering the influence of the geological substrate, soil, slope and vegetation cover. It follows
103　assessing the potential permeability (physical factor) together with the ability to infiltration given
104　by vegetation. It is called Current Permeability, because it considers information on the current
105　land use" [21].
106　　　It was necessary to convert from the raster format to vectorial format, described in the land
107　steepness map, being the selected criteria of the current permeability for each culture identified
108　as follows:
109　•　　Cardoon: does not tolerate areas with waterlogging, having preference for well drained soils,
110　　　　being selected the parameters of "moderate to high—class 4" and "high—class 5", since the
111　　　　water infiltration should be as high as possible.
112　•　　Miscanthus: it copes well with soils with high capacity of water retention, therefore, it is
113　　　　tolerant when the infiltration is low, being selected only the "low—class 1" value.
114　•　　Paulownia: the same criteria previously considered for cardoon were selected.

115   Figure S5 shows the parameters previously detailed (the presence of physical obstacles,
116   ecological soil value and current permeability).

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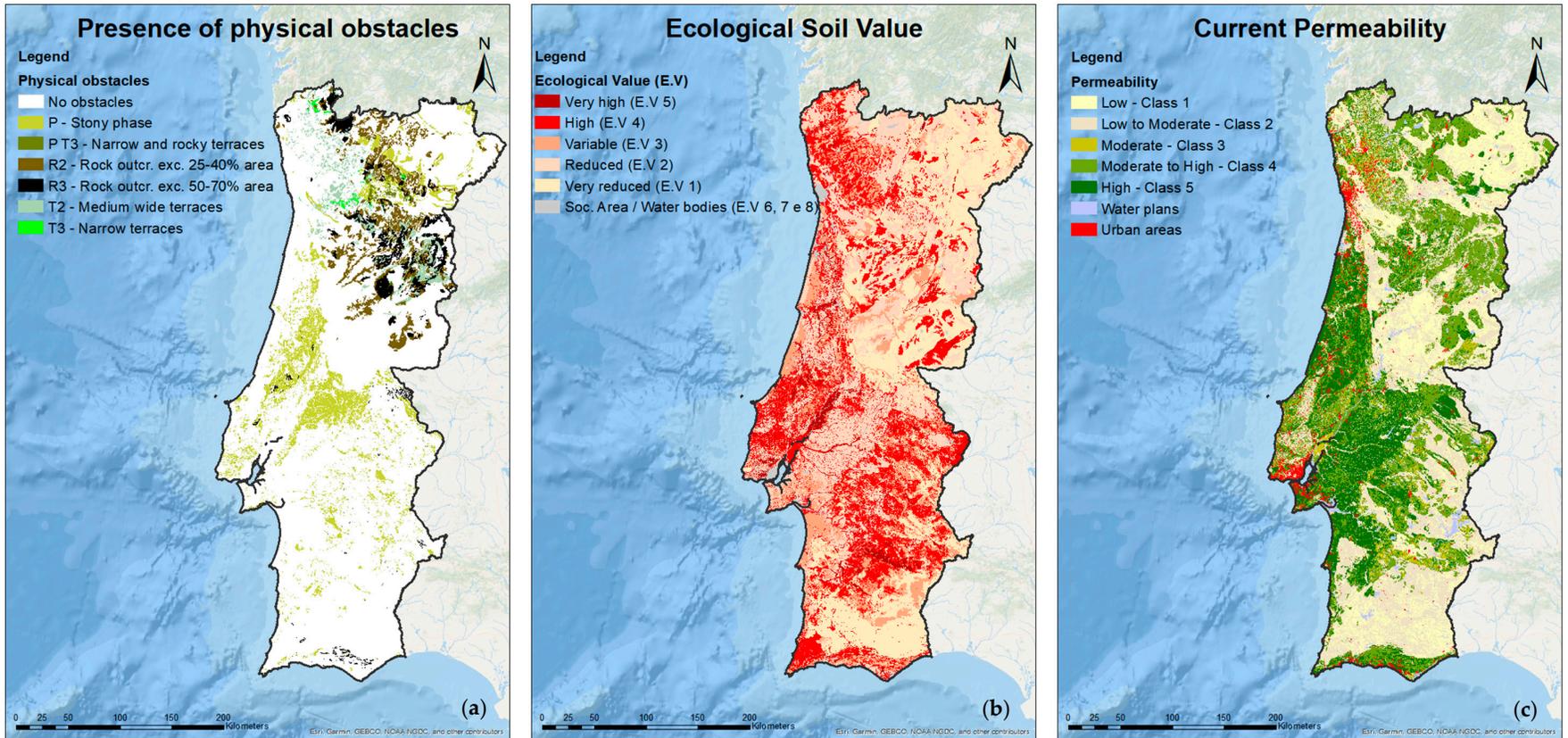
118   **Figure S5.** Maps according to EPIC WebGIS platform (ISA-UL): (**a**) Map of the presence of physical obstacles; (**b**) Ecological Soil Value Map; (**c**) Current permeability.
119   (Adapted from [19–21]).

120 *S.3.8 Natural and semi-natural vegetation with conservation value*

121   This map allows the "identification and assessment of areas where natural and semi-natural
122 vegetation with conservation value. Among the most relevant ecosystems services derivable of
123 this information are the preservation of plant biodiversity (species) and the conservation of plant
124 communities' integrity (habitats) and vegetation mosaics (complex of habitats). This process
125 considers not only the intrinsic value of the mapped communities, but also the potential
126 occurrence of rare or endangered plants in them" [22].

127   The selected criteria for each culture are described below:

128 •   Cardoon, miscanthus and paulownia: for the three species, the criteria that correspond to
129   "low" and "very low" conservation value were selected, once these areas are the most
130   suitable for energy crops.

131 *S.3.9 Soil-morphological aptitude to irrigated agriculture and silviculture*

132   This map represents the "partial suitability dependent on soil, land morphology and slope
133 conditions. This suitability was determined for the Rainfed and Irrigated Agriculture and the
134 Silviculture and aimed to restrict the suitability to Agricultural Crops and Tree Species/Pastures
135 to the most suitable conditions in respect of those parameters. The Soil and Morphological
136 Suitability for Rainfed Agriculture was determined from an array that integrates the ecological
137 value of the soil with the land morphology and the slope" [23].

138   In order to create the maps, it was necessary to perform the conversion from raster format
139 to the vectorial format, described in the land steepness map, being the selected criteria as follows:

140 •   Cardoon and miscanthus: the soil-morphological aptitude to irrigated agriculture was
141   applied only to these two species because they are herbaceous, being selected the parameters
142   that correspond to "without aptitude—25.3%" and "low—34.7%", related to areas not
143   suitable for food crops.
144 •   Paulownia: the soil-morphological aptitude to silviculture was only applied to this species
145   due to the fact that it is the unique forest type, being just selected the parameter "forestry
146   not recommended—15.7%" that corresponds to areas not appropriate for food crops.

147   Figure S6 presents the parameters previously described (the natural and semi-natural
148 vegetation with conservation value, soil-morphological aptitude to irrigated agriculture and
149 silviculture).
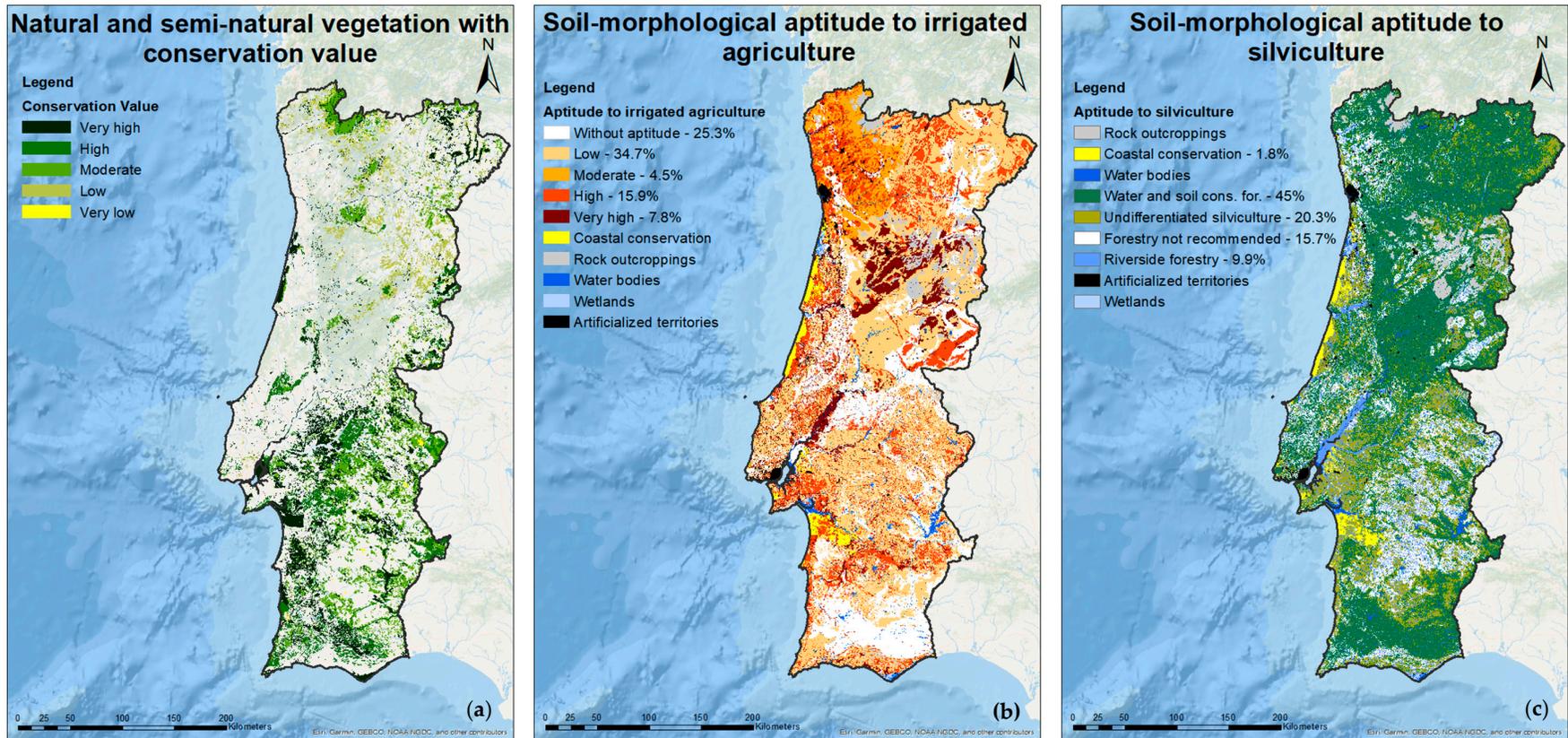
150
151 **Figure S6.** Consulted maps from EPIC WebGIS platform (ISA-UL): (**a**) Natural and semi-natural vegetation with conservation value map; (**b**) Soil-morphological
152 aptitude to irrigated agriculture; (**c**) Soil-morphological aptitude to silviculture. (Adapted from [22–24]).

153 **S.4. Consulted Maps from Instituto da Conservação da Natureza e das Florestas (ICNF)**

154 *S.4.1 Protected areas*

155   The protected areas are identified by the following categories:

156 • Important Community Sites (SIC) (Natura 2000): "sites in the Atlantic, Mediterranean or
157   Macaronesian biogeographical region(s) that contribute significantly to maintaining or
158   restoring a natural habitat type …, in a favorable state of conservation, and may also
159   contribute significantly to the coherence of the Natura 2000 Network or to maintain
160   biological diversity in the biogeographic regions referred" [25].
161 • Protected Special Zones (ZPE) (Natura 2000): "ZPE limits - established under the Birds
162   Directive, which are primarily intended to ensure the conservation of bird species and their
163   habitats… and migratory bird species … whose occurrence is regular" [26].
164 • Protected Areas National Network (RNAP): "consists of the boundaries of protected areas
165   classified under Decree Law No. 142/2008 of 24 July. The inland terrestrial and aquatic and
166   marine areas are classified as protected areas, where biodiversity or other natural
167   occurrences have, for their rarity, scientific, ecological, social or scenic value, a special
168   relevance requiring specific conservation and management measures" [27].
169 • Ramsar Sites (wetlands): "international wetland network that is important for the
170   conservation of global biological diversity and sustainable human development through the
171   maintenance of components, processes and benefits/services from ecosystems" [28].
172 • Biosphere Reserves (areas classified under international commitments): "these are
173   representative samples of marine, terrestrial or coastal ecosystems where solutions are
174   promoted to reconcile biodiversity conservation with sustainable use, internationally
175   recognized (UNESCO's Man & Biosphere Program). Throughout their zoning in area(s)
176   Core, Buffer and Transition areas. Only the Core area needs legal protection and may
177   correspond to a pre-existing protected area such as a reserve or nature park" [29].
178   All maps of protected areas are available in the Instituto da Conservação da Natureza e das
179 Florestas - ICNF Geocatalog.

180 *S.4.2 Unprotected areas*

181   Map with all areas of mainland Portugal that do not include protected areas (layers
182 identified in S.4.1 as Important Community Sites - SIC, Protected Special Zones - ZPE, Protected
183 Areas National Network - RNAP, Ramsar and biosphere reserves) being created from this data
184 and the "Official Administrative Charter of Portugal - CAOP 2017" (districts map), in order to
185 represent the unprotected areas and areas where crops are allowed.
186   This map was considered for the four types of biomass (cardoon, miscanthus, paulownia
187 and microalgae) as a way to avoid the use of prohibited areas identified as protected areas.

188 *S.4.3 Soil susceptibility to desertification*

189   Areas with soil susceptible to desertification that are part of the "Rural Development
190 Program - PDR 2020 Support Mapping. The indicator presented corresponds to the intersection
191 of the Soils Susceptibility to Desertification chart presented in Rosario 2004 and the areas of
192 parishes reported in CAOP 2016 (DGTerritory), covering the most updated territorial and
193 administrative boundaries for the mainland territory" [30].
194   The selected criteria for each culture are specified below:

195 • Cardoon, miscanthus and paulownia: the criteria that correspond to "3—High" and "4—
196   Very high" were selected, being the highest values, therefore, areas not appropriate for food
197   crops.

198   Figure S7 shows the criteria previously described (protected and unprotected areas and soil

199   susceptibility to desertification).

200
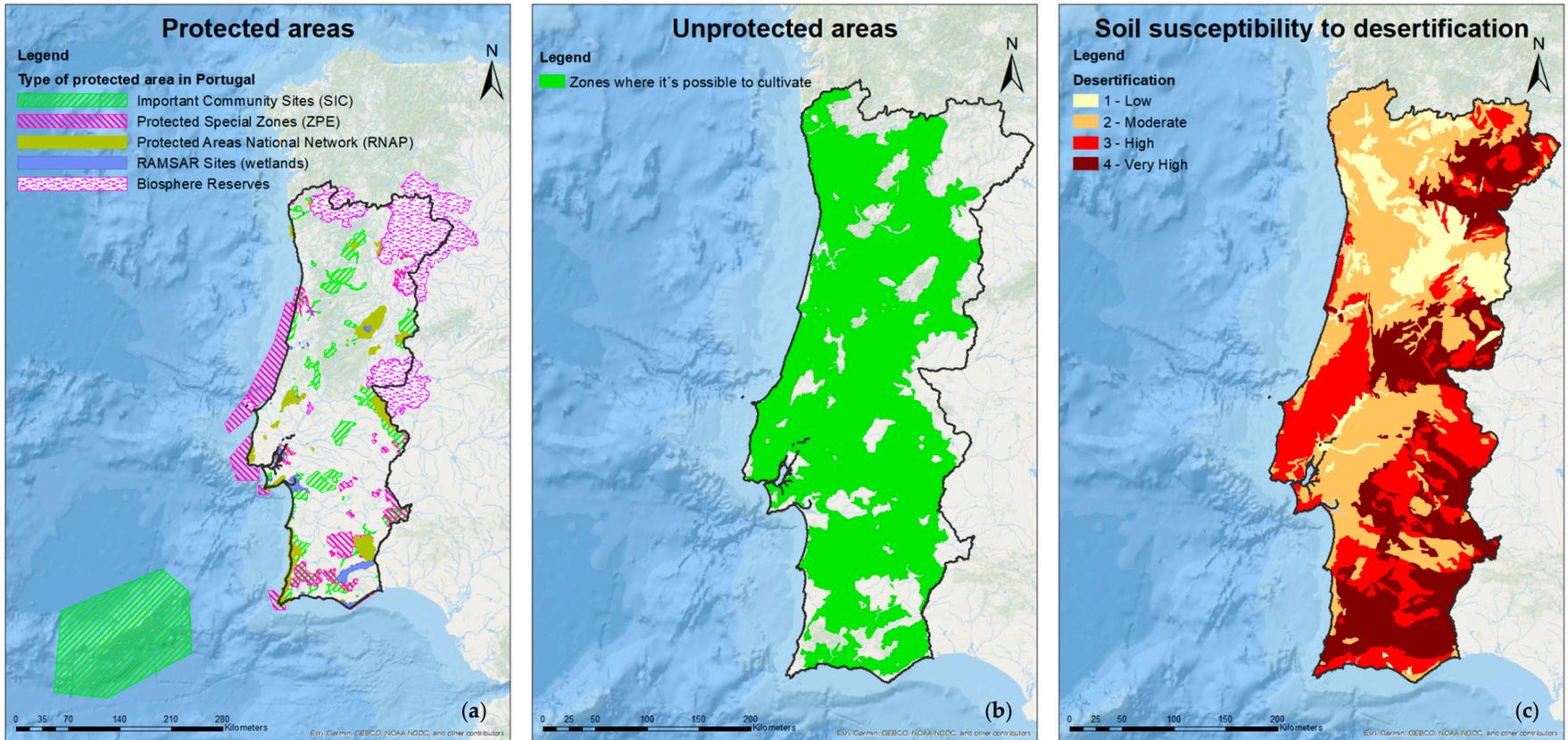
201
202 **Figure S7.** Maps obtained from ICNF: (**a**) Protected areas in mainland Portugal corresponding to areas not permitted for cultivation; (**b**) Unprotected areas,
203 corresponding to zones where cultivation is allowed; (**c**) Soil susceptibility to desertification. (Adapted from [1,30,31]).

204 **S.5. Maps from Empresa de Desenvolvimento Mineiro (EDM) - Classification of soils**
205 **according to each mine group (Contaminated soils)**

206 Mines location points (not areas) that integrate the EDM's environmental remediation
207 concession, including the group to which they belong (radioactive and polymetallic),
208 representing the contaminated soils.
209 This map is relevant for the three species (cardoon, miscanthus and paulownia) as relates to
210 highly contaminated areas, therefore, suitable for further implementation of non-food crops and
211 with high potential for energy crops production.

212 **S.6. Maps obtained from European Environment Agency (EEA)**

213 *S.6.1 Wastewater Treatment Plant (WWTP) capacity*

214 It represents the capacity that can be processed in the Wastewater Treatment Plant - WWTP
215 in population equivalent (p.e) units [32].
216 There are many benefits associated with the use of wastewater in irrigation [33]:

217 • Decreases the demand for ground and surface water, ensuring the preservation of current
218 water resources.
219 • The presence of nitrogen, phosphorus and other elements in the wastewater reduce the need
220 of fertilizers, reducing the Greenhouse Gases - GHG emissions associated with. In addition,
221 the use of these waters, enriched with nutrients, may result in higher growth and
222 productivity of the species, thus creating greater carbon sequestration.
223 • The water composition may restore the nutrient and the biological balance of the soil; the
224 use of wastewater contributes to restore groundwater levels.
225 • As part of the wastewater is sent to the crops irrigation, there is a lower consumption of
226 energy and chemicals in the process of purification and treatment of water in the WWTP,
227 which means lower cost for the installation and lower presence of contaminants in the water
228 bodies.
229 • It generates significant economic benefits by lowering overall cultivation costs, especially in
230 areas where water resources are scarce.
231 On the other hand, the use of wastewater for irrigation has also some constraints [33]:
232 • This practice is only feasible for distances not exceeding 3 km between the WWTP and the
233 cultivation area.
234 • The low water flow in WWTPs located in areas with low population density, is a factor that
235 reduces the amount of this resource for irrigation. The installation of wastewater storage
236 systems in the cultivation area can be necessary, in order to save Wastewater - WW for
237 periods of water stress.
238 • The chemical and biological composition of WW can vary over time and by area, so it is
239 necessary to verify the average composition of these effluents. The presence of contaminants
240 may negatively affect the crop (yields and biomass quality), the soil and the groundwater.
241 This map has been considered for the following crops:
242 • Cardoon, miscanthus and paulownia: it applies to all three species, for every WWTP placed
243 close to the cultivation area, their water can be used as irrigation water, when precipitation
244 is not sufficient, to avoid water stress.
245 • Microalgae: the production of microalgae can be associated with the applied wastewater
246 treatments in the WWTP; the substances still present in the treated waters guarantees the
247 growth and development of the microalgae, and their accumulation in the biomass results
248 in the depuration of the water before its discharge.

249 *S.6.2 Applied treatments to Wastewater Facilities*

250 Represents the type of applied treatment to the processed waters in the WWTP [32].

251   The data are identified in the same shapefile created in the previous segment, being only
252 different the represented values, namely, the column designated as "Treatment" that identifies
253 the type of applied treatment in the wastewater before its discharge, in order to know the water
254 quality.
255   This map, as in the previous case, was considered for the following crops:

256 •   Cardoon, miscanthus and paulownia: map considered for the three species, being advisable
257   that the WWTP provides Secondary treatment or Tertiary treatment to guarantee water with
258   the desired quality for irrigation.
259 •   Microalgae: if the WWTP presents only the Primary treatment, the microalgae can be
260   incorporated in the system to assist the water purification before of its discharge.
261   Figure S8 shows the parameters previously detailed (contaminated soils, WWTP capacity
262 and applied treatments to Wastewater Facilities).
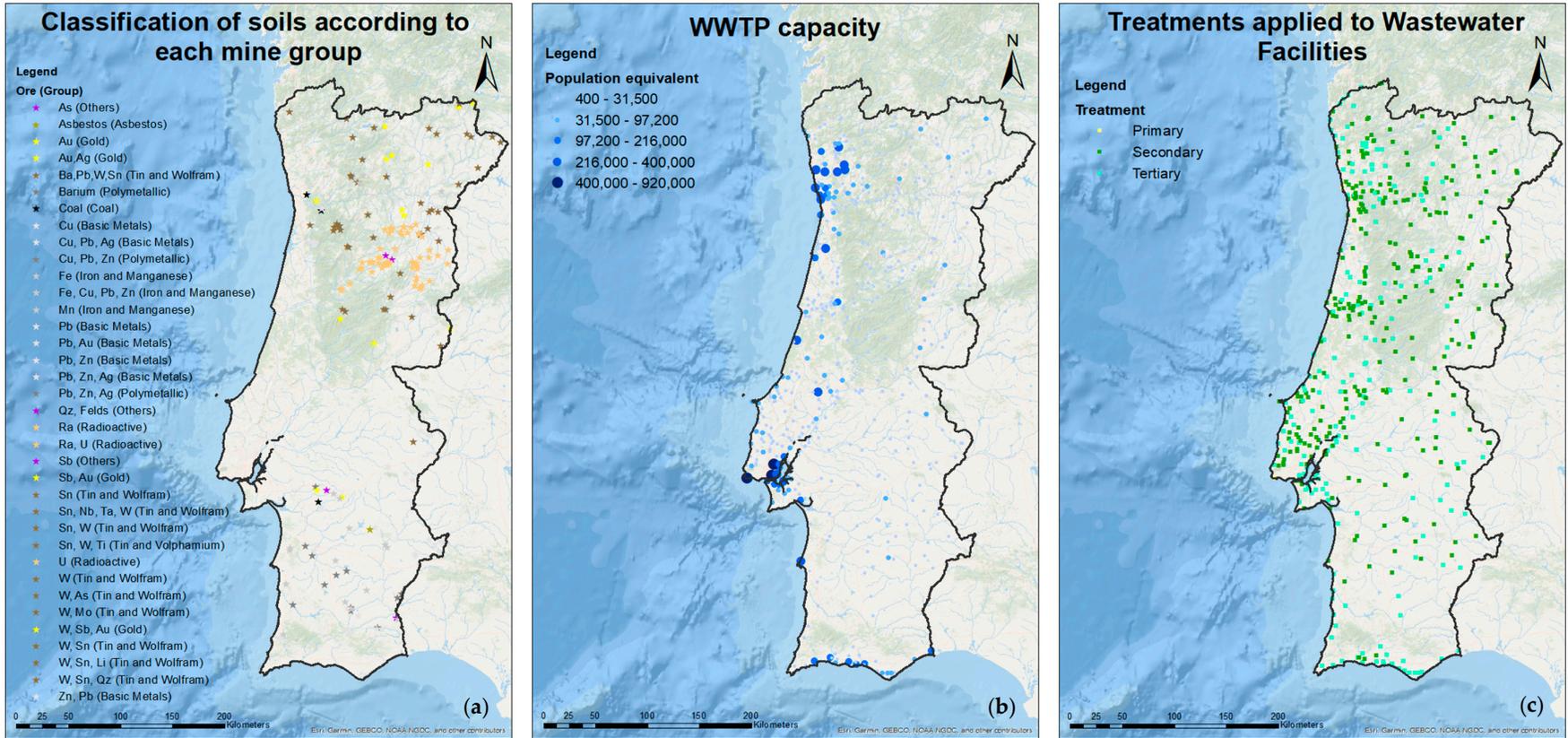
263
264   **Figure S8.** Maps according to EDM and EEA data: (**a**) Mines that are being recovered by EDM (contaminated soils); (**b**) WWTP capacity in mainland Portugal; (**c**)
265   Treatment applied in WWTPs. (Adapted from [32,34]).

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