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Deliverable 2 - Technical report on methods and tools in support of the creation of an “IACS carbon theme”

JRC Project “Satellite based mapping and monitoring of European peatland and wetland for LULUCF and agriculture”

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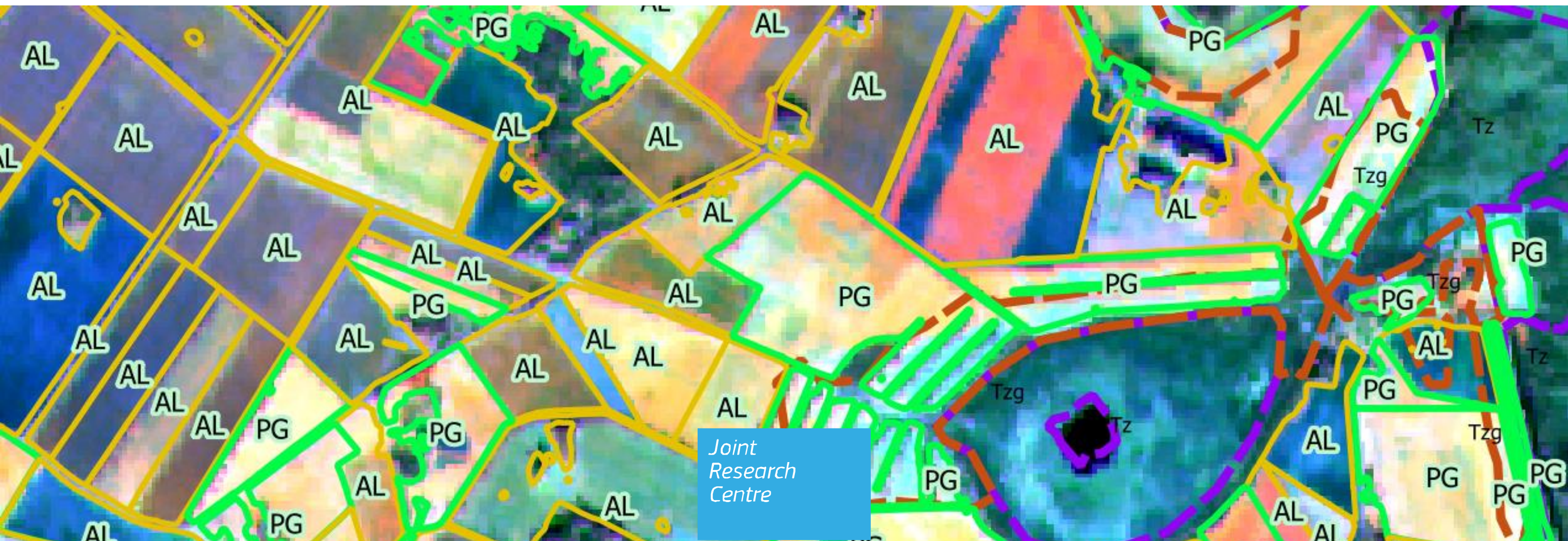

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Abstract

SEPLA stands for “Satellite based mapping and monitoring of European peatland and wetland for LULUCF and agriculture”. The main objective of the project is to ensure a comprehensive inventory of wetlands and peatlands and to address the monitoring of their preservation and restoration, by remote sensing and regularly updated geo-datasets.

This report, considered as the second deliverable of the project, elaborates on the possible technical choices the EU Member States could apply to combine and integrate the spatial data on organic soil and related environmental conditions with the datasets of the Land Parcel Identification System (LPIS), a component of the Integrated Administration and Control System (IACS). The objective of the methods and tools is to determine the agricultural areas subject to the GAEC standard 2 on the protection of wetland and peatland, given the specifications and the potential limitations of the source data.

The report concludes that the introduction of the GAEC 2 information in the LPIS should be performed in the most efficient and effective way possible, with minimal changes to the LPIS design and its update process. It provides further insight on how already existing CAP-related spatially-explicit datasets may be used in combination with CAP satellite-based remote sensing systems in place, and how additional data within these datasets should be cost-efficiently collected, to ensure that CAP-strategic plans fulfil the targets and quality needs of LULUCF Regulation 2018/841.

Foreword

This report presents some results of the project SEPLA (Satellite based mapping and monitoring of European peatland and wetland for LULUCF and agriculture), on the methods and tools to determine the agricultural areas on organic (and eventually organic-rich) soils subject to the GAEC standard 2 on the protection of wetland and peatland. The project is defined under the work program signed between DG JRC and DG CLIMA, and implemented by the GTCAP team of JRC D5 Unit (Food Security). This report relates to Deliverable 2 - Technical report on methods and tools in support of the creation of an "IACS carbon theme". Although, the territorial scope of this document is the agricultural area recorded in the Integrated Administration and Control System, land that is part of the farm holdings applying for CAP payments, the proposed methodology is equally applicable for other managed land and related policy where the information on soil and associated environmental conditions, is of key relevance.

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1 Introduction

This report builds upon the lessons learned from the data integration methods defined in Deliverable 1 of the SEPLA project (Milenov et al., 2022). It elaborates the possible technical choices to combine and integrate the spatial data on organic soil and related environmental conditions with the datasets of the Land Parcel Identification System (LPIS), a component of the Integrated Administration and Control System (IACS). The objective of the methods and tools is to determine the agricultural areas on organic (and eventually organic-rich) soils subject to the GAEC[1] standard 2 (GAEC 2) on the protection of wetland and peatland, given the specifications (scale, accuracy) and the potential deficiencies (gaps, uncertainties) of the source data. The method inventories the geospatial data on the IPCC[2] wetland sub-categories relevant for the reporting of the greenhouse gas (GHG) emissions from the land use, land-use change and forestry (LULUCF) sector, and identifies those subjected to CAP conditionality (GAEC 2). The report also tackles the need for spatial data on wetlands and organic-rich soil relevant for the CAP eco-schemes and Rural Development (RD) measures, potentially enhancing the consistency between CAP and LULUCF reporting at the EU Member State level.

The report could be considered as a "good practice" document, as it adheres to the principles and concepts laid down in the Technical Guidance for the Management of layers in LPIS (Luketic et al., 2015). Its target readers are the technical experts in the EU Member States Administrations, responsible for the GAEC 2 implementation and those involved in the management and upgrade of the LPIS. The report deals with the technical aspects of the integration of spatial data that are different in nature, in cartographic scale and the application area, and proposes possible methods for handling and representing the spatial information on soil and wetness status, associated with the LPIS reference parcel. It specifically focuses on the implied uncertainty of the boundaries of soil and wetland-related representations on a map, due to the diffuse character of the spatial extent of soil units and wetland ecosystems.

[1] GAEC: Standard for good agricultural and environmental condition of land
[2] IPCC: Intergovernmental Panel on Climate Change

2 Regulatory and conceptual framework

2.1 GAEC 2 standard in the EU legislation

The protection of organic (and relevant organic-rich) soils in agricultural peatlands and wetlands is a GAEC standard under the Common Agricultural Policy (CAP) that entered into force in January 2023. Member States (MS) can delay their application of GAEC 2 until the claim year 2024 or 2025, if necessary, for the establishment of an identification of the area concerned and management system. The GAEC 2 aims to stop further organic soil degradation and peatland deterioration, through specific “baseline” conditions defined by each EU Member State, such as: a ban on drainage, a ban on ploughing, a ban on peat extraction, or extensive management of permanent grassland.

The secondary CAP legislation (Article 2(7) of Commission Delegated Regulation (EU) 2022/1172) provides the following indications for the information on wetland and peatland in the LPIS:

> *“In the identification system, for each reference parcel Member States shall at least:*
>
> *(d) include features and/or commitments that are relevant for the eligibility of area-based interventions and for conditionality requirements, and are stable in time. This information shall be recorded as attributes or layers in the identification system for agricultural parcels and at least the following shall be indicated:*
>
> *(i) the location of peatland or wetland area, where relevant, in accordance with GAEC standard 2 listed in Annex III to Regulation (EU) 2021/2115;…...”*

Furthermore, a footnote in Annex III of Regulation (EU) 2021/2115 clarifies that: "Member States, when establishing GAEC standard 2, shall ensure that on the land concerned an agricultural activity suitable for qualifying the land as agricultural area may be maintained."

This means that the LPIS should be able to identify the presence and location of areas under agricultural management and relevant for CAP support that are on organic and organic-rich soils, originated from peatland ecosystems in the past. This information could be stored within the LPIS setup either geographically or alphanumerically. These areas with these soils could manifest typical, persistent bio-physical characteristics such as wetness, when not drained, or dark colouring of the surface, when bare. The characteristics of peatland are defined at the national level, usually by such terms as: minimal soil organic carbon content, minimal depth to the organic horizon and/or specific wetness status.

2.2 Scope of GAEC 2 and its representation in LPIS

The CAP legislation stipulates that GAEC 2 (as any other GAEC standard) applies to all agricultural areas, including land which is no longer used for production purposes. In particular, Member States shall provide in their CAP Strategic Plans the definition of agricultural area as framed in Regulation 2021/2115. The Regulation defines result indicator R.14 *“Carbon storage in soils and biomass” as “Share of utilised agricultural area (UAA) under supported commitments to reduce emissions or to maintain or enhance carbon storage (including permanent grassland, permanent crops with permanent green cover, agricultural land in wetland and peatland)”.* For the SWOT analysis of the current situation, the Regulation introduces a context indicator C40 "Soil organic carbon in agricultural land". As a result, it is important to have the correct understanding of the terms “agricultural area” and “agricultural land”. Some clarifications are provided below.

The geographic scope of GAEC 2 is limited by the spatial extent of the “agricultural area”, which is defined by the EU Member States, based on the framework definitions of arable land, permanent grassland and permanent crop as set in Article 4 of Regulation (EU) 2021/2115. It also includes agroforestry systems where they could be qualified in terms of land cover to any of these three categories. Permanent grasslands with scattered ineligible features under pro-rata are also part of the agricultural area. The agricultural area could include also non-productive areas, such as landscape features, subject to GAEC 8 (non-productive areas and features). Land no longer used for production purposes should be understood as an area on which agricultural production does not take place, but which by means of an agricultural activity is maintained in a good state suitable for production. It still qualifies as either arable land, permanent grassland or permanent crop. Member States shall provide in their CAP Strategic Plans the definition of agricultural activity and agricultural areas as framed in Article 4 of Regulation 2021/2115.

Although there is no pan-EU definition of “agricultural land” in the CAP legislation, the general understanding is that from the land cover perspective, it encompasses the agricultural areas (which are by default subject to the GAEC2) and other non-agricultural areas, defined by the EU Member States not being subject to the GAEC 2 but potentially eligible for RD measures.

Mineral wetlands are not considered subject to GAEC 2, when they don’t form an organic layer.

Peatlands kept in a natural state and located in non-agricultural areas are not subject to GAEC 2, as they do not fall within the definition of agricultural areas. The same could apply to former agricultural areas impacted by Natura 2000 and long-term set-aside or afforestation in the context of Art. 4(4)(c) 2021/2115. This depends on whether these areas, impacted by the mentioned commitments/obligations, remain agricultural areas. Both peatlands and former agricultural areas can be nevertheless subject to RD measures under the EU CAP.

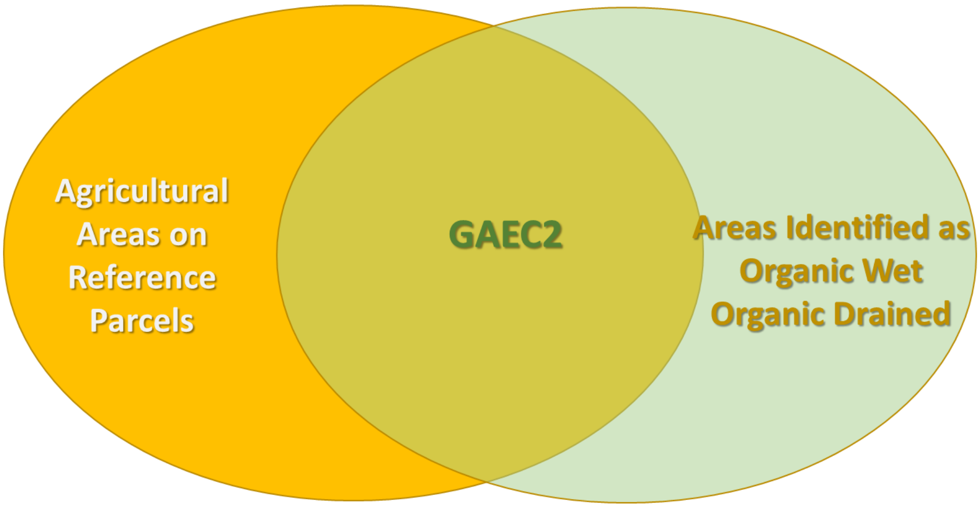
Article 2(7)(d) of Commission Delegated Regulation 2022/1172 provides sufficient flexibility on how MSs account for the information on organic soils in the LPIS. Nevertheless, at a minimum, the LPIS should provide information on which reference parcels are subject to the GAEC 2, without the need to provide explicitly a quantitative value on the share of the area of organic soils within the reference parcel. In case of partial coverage, there should be some indication of the location of the area on organic (or organic-rich) soil within the reference parcel. This location could become evident once the reference parcel is overlaid with the vector or raster datasets, holding the relevant information.

The elaboration of the “IACS carbon theme” implies that each LPIS reference parcel is cross-checked with spatial data and information on organic soils and related environmental conditions. The latter data relates to various aspects of the phenomenon present on the ground (soil characteristics, wetness, terrain, hydrological conditions, land cover, possible wetland ecosystems present, etc.); it can be in different formats (vector, raster) and product specifications (scale, coverage, thematic information). Deliverable 1 of SEPLA (Milenov et al., 2022) tried to group and “reduce” this data into a few distinct sub-categories relevant to the key IPCC categories: Organic Wet, Organic Drained and Mineral Wet. The first two - Organic Wet, Organic Drained - cover the areas relevant to the GAEC 2 and will be addressed in detail in this document (**Figure 1**). Although relevant for the LPIS in the context of Art. 2(7)(g) of Regulation 2022/1172, areas related to Mineral Wet are not covered, as they do not strictly form a part of the “IACS carbon theme”. The relevance of the mineral wetlands (especially the coastal Mediterranean ones) in the context of carbon stocks and emissions will be subject to future technical and research projects.

Box 1. Setting up the threshold Soil Organic Carbon

The methodology in SEPLA Deliverable 1 stipulates that a part of the source data on soil type and wetness status will be grouped in another spatial layer, called "Organic-Rich". These are wet or drained areas on organic soils having Soil Organic Carbon (SOC) between 20% and 6%, often resulting from pristine peatland degradation. The SOC threshold of 20% between organic and organic-rich soils reflects the needs of IPCC and the current accepted FAO definition (the definition of organic soils is considered equivalent to the one of Histosols). However, for the needs of GAEC2, EU Member States might set a different SOC threshold, reflecting the national approach to peatlands and the local conditions (some EU MS might set the thresholds to 30%, while others to 12%). This means that if EU Member States use the SEPLA Deliverable1 to identify the areas relevant for GAEC 2, they should revise the initial spatial extent of "Organic Wet" and "Organic Drained" layers according to their locally adopted SOC thresholds. The revised spatial layer on Organic-Rich will then reflect areas being out of GAEC2 scope, but potentially subject to the CAP eco-schemes and RD measures.

Figure 1. Diagram showing the territorial (spatial) extent of the GAEC 2, resulting from the intersection between the agricultural areas on reference parcels (LPIS), as defined by Art. 4(3) of 2021R2115 and areas identified as organic wet or organic drained (revised with locally applicable SOC thresholds).



Source: GTCAP

2.3 Terms and definitions related to wetlands and peatlands

There is a need to start from the peatland and wetland definitions to understand whether, with the available tools at hand, one could find physical evidence on the ground confirming the presence of peatland/wetland-related organic soils within the reference parcel.

There is no single definition of wetland/peatland that all stakeholders, scientists, policymakers, or landowners use for all purposes. The assessment of the different definitions provided by the different expert communities for the different application areas reveals that three aspects appear in all definitions: hydrology, soil and vegetation. The water plays a central role as a defining feature. The presence of substrate or soils formed under saturated conditions (hydric soils) and the presence of vegetation adapted for saturated conditions (hydrophytic vegetation) are the other essential factors for the environment of the wetland ecosystem (Heimlich et al., 1998).

In the LULUCF and GAEC 2 context, wetland could be considered as an area:

— Of natural origin,

— With constant or recurrent shallow inundation or water saturation at or near the surface of the substrate,

— Where anaerobic conditions occur in the upper part of soils (hydric soils), saturated for lengthy periods of time during the growing season,

— Where specific hydrophytic vegetation is developed, forming particular ecosystems,

— That could be subject to management limited by natural constraints, such as limited soil drainage.

Based on the wetland definitions and the work of the International Mire Conservation Group (IMCG), peatland could be regarded as a subtype of wetlands and could be considered as areas, sharing the characteristics above, and further:

— Having a naturally accumulated layer of organic deposits, present at the surface or located at a certain depth beneath, with a certain thickness and concentration of soil organic carbon,

— With specific hydrophytic vegetation developed according to the organic soil and environmental conditions, forming a specific ecosystem,

— Associated often with particular landforms and hydrological connectivity determining its formation and evolution.

The persistence of an adequate water table is vital for the sustainable and healthy state of the peatlands. The seasonal fluctuations of the water table induce vertical surface movements of peat from a few to tens of centimetres per year (Howie and Hebda, 2017) due to the "sponge" effect - the peatlands expand when saturated with water, while they shrink when dry. When peat is degraded, for example by fire or drainage, its water retention capacity is greatly reduced. Drainage and cultivation of peatland cause oxidation and surface subsidence, strongly altering the physicochemical characteristics and the capacity to store C and other GHG.

It is evident that wetlands and peatlands have certain distinctive observable characteristics that allow for their identification and mapping. Peatlands under agricultural management had their naturally occurring vegetation removed but could have the soil and hydrologic conditions preserved. The main challenge in the identification of such areas is that when used for agriculture, they manifest an appearance typical for agricultural land cover (arable land, permanent crop, permanent grassland), since the peat layer is “hidden” beneath the cultivated and managed vegetation. Moreover, what is left of the original physicochemical characteristics of the peat layer (e.g. thickness, soil organic carbon content, wetness) can be little and depends on the intensity and the time since the perturbation happened.

Box 2. Terms and Definitions

It cannot be overstated that when referring to wetlands and peatlands in the context of the GAEC 2, one should refer to agricultural areas originating from natural peatlands and wetlands. Consequently, some terms, such as organic soil/horizon and peat layer, are used in the document in an equivalent manner (as synonyms).

Inevitably, the methodology for the creation of this IACS carbon theme would need to deal with a variety of characteristics of the peatland, some of which will be manifested on the surface and, in practice, observable through satellite-based (or aerial-based) methods or through visual assessment (complemented with geotagged photos) made on the field. These observable characteristics will play an essential role in the assessment of the reference parcels subject to GAEC 2 and their subsequent monitoring. For any non-observable characteristics (for example, soil pH), considered essential for the delimitation of the peat layer in the local context, soil sampling may be considered.

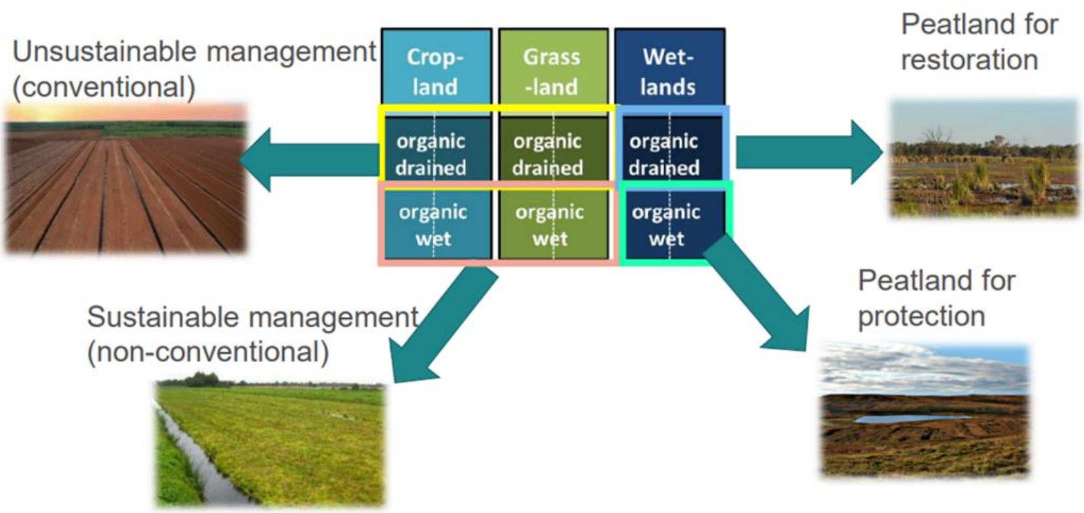
3 Methodological approach for creation of IACS "carbon theme"

3.1 General principles

The "IACS carbon theme" should be understood as a combination of spatial and alphanumeric data on organic soils and their related environmental conditions, located within the agricultural areas delimited on reference parcels. The theme should indicate the parts within the LPIS reference parcel where the GAEC 2 standard is applicable. This data further helps to locate areas where specific peatland protection and restoration measures could be defined as part of the CAP eco-schemes and RD measures (**Figure 2**). One can state that **the scope of the GAEC extends to those organic and, wherever relevant, organic-rich soils that originate from peatland and wetland formation**. The criteria to define reference parcels under GAEC 2 should be (if not already) aligned with the peatland and wetland definitions applied for LULUCF-related reporting (Milenov et. al, 2022).

Consequently, the building up of a pertinent "carbon theme" in IACS would require the introduction in the LPIS data management process, of spatial data and information on soil carbon (presence of an organic horizon, depth, carbon content), the wetness of the land and a link to the vegetation cover. Consequently, this will require, whenever possible, the collection of any additional information (for example, vegetation type and strata) that could indicate and reveal the underlying soil and wetness conditions, and the presence (or the original presence) of a peat layer. This could even involve any data on the status of wetland ecosystems in general such as floristic aspects, key or indicator species distributions, and vegetation cover or phenological spatial-temporal patterns.

Figure 2. IPCC sub-categories and some possible CAP interventions related to peatlands. Note: The IPCC sub-categories were proposed in the 2013 wetland supplement to IPCC guidelines as good practice to subdivide each land use/conversion category into subcategories with similar characteristics.



Source: GTCAP

The selection of the optimal technical choice to accommodate the "GAEC 2-related" data in an LPIS, is determined by the answers to the following three basic questions:

1. Is there a need for an update of the existing layers in the LPIS - mainly the reference parcel perimeter and associated attributes (reference area, land cover type)?
2. What would be the advantage of the introduction of extra attributes in the LPIS datasets to reflect GAEC 2-related properties of the area represented by the reference parcel (for example, to record the soil organic carbon content or the presence of an organic horizon)?
3. Can the GAEC 2-related data and information be kept independently from the core LPIS layers/datasets, either stored within the LPIS setup or accessible through web-based services? Could any relevant assessment be then performed on-the-fly?

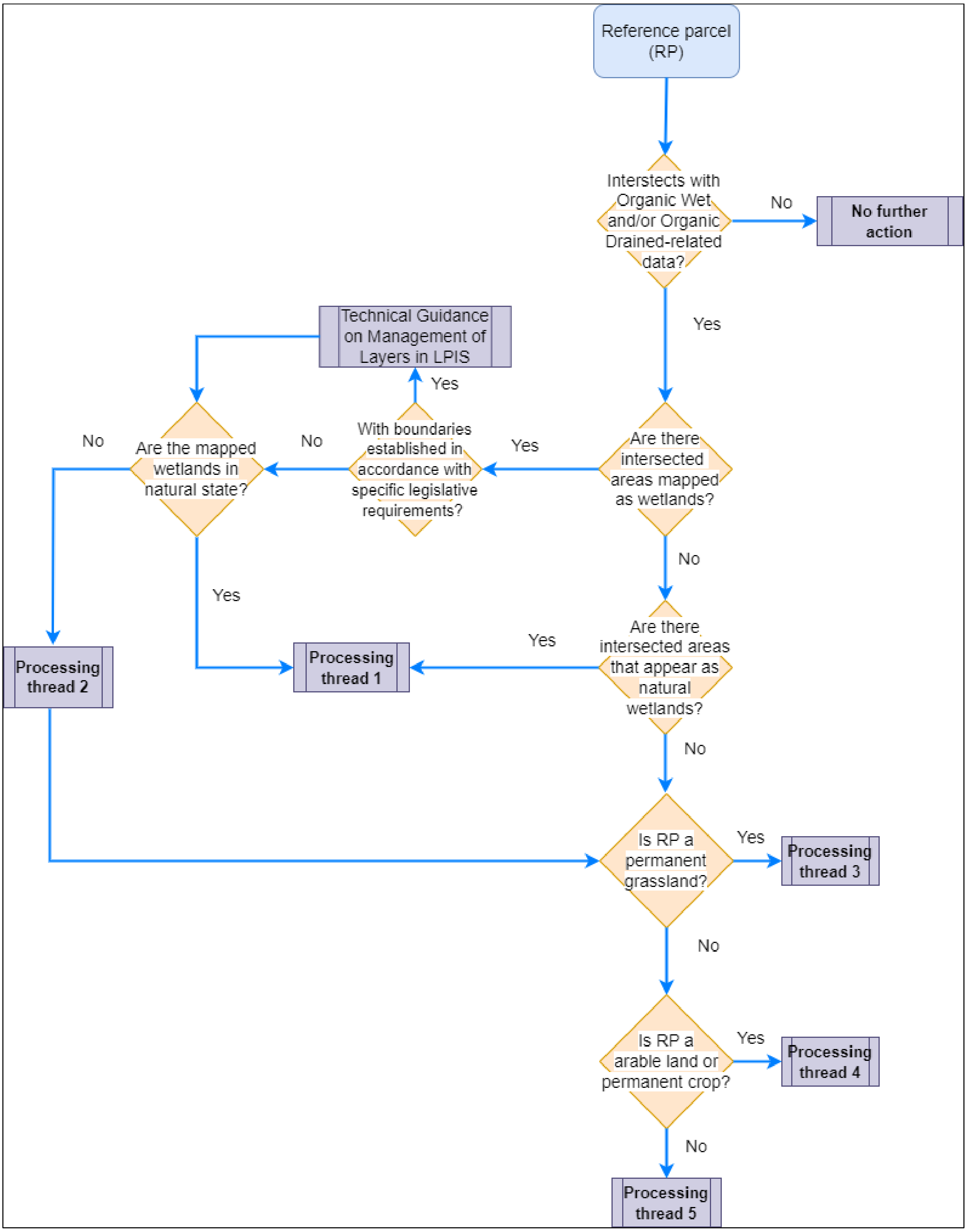
The answers to the above questions largely depend on factors, such as: the type of GAEC 2-related data; the local LPIS implementation; the organization of the LPIS update; the technical setup of the farmer application process in the Geospatial Aid Application (GSAA); the available national spatial data infrastructure; and others. The guiding principle of the methodological approach will be to induce as few changes as possible in the LPIS design. The underlying idea is to integrate the information collected on wetlands/peatland in a way that allows the generation of most of the information "on-the-fly". Yet, as previously mentioned, there might be a preference to introduce specific attributes to account for the wetland and peatland areas that are potential candidates for preservation and restoration.

3.2 Data integration process and related application options

Figure 3 provides an illustration of a possible workflow, identifying the decision ruleset, to guide towards the appropriate **processing thread**. Each processing thread, uniquely numbered, contains guidance on the possible actions to perform within the LPIS environment. The selection of a given thread depends on the type of agricultural land cover of the reference parcels, the type of input data impacting the given reference parcel (mapped wetlands, wet/drained organic soils), and the metadata on the source datasets involved. The workflow accommodates the case where both spatial layers of Organic Wet and Organic Drained could be present simultaneously within the reference parcel perimeter. Multiple processing threads could be applicable to a single reference parcel.

The proposed workflow and associated threads aim to provide a comprehensive overview of all possible actions. **The application of any of these actions (partially, in full or not at all) is completely a discretionary decision of the Member States, to be made in line with their LPIS design, information needs and adopted LPIS update process.**

Figure *3.* Decision workflow (ruleset) to guide the reference parcels towards the possible processing thread (details in section 3.2.1).



Source: GTCAP

The processing flow in **Figure 3** assumes in principle that the agricultural area represented by the reference parcel relates to only one type of agricultural land cover. It should be noted that there will be cases when the reference parcels will enclose areas with more than one agricultural land cover type. However, these areas within the reference parcel are supposedly already delineated, as spatial objects with their own identifiers (IDs), in line with the technical modalities provided in the LPIS guidance document from 2018 (DS/CDP/2018/11). In the context of the ruleset given in **Figure 3**, these spatial objects can be treated as reference sub-parcels and processed in the same manner as the reference parcels.

The methodology for identification and mapping of candidate peatlands and wetlands areas for LULUCF identifies two possible application options for data integration to create the IACS carbon theme:

1. Application option 1: when the LPIS should deal with classified (labelled) data related to wetland and soil, provided (but not exclusively) in vector format.
2. Application option 2: when LPIS should deal mainly with continuous (measurement) data, largely provided in raster format.

Both application options are discussed in detail in the following sections.

3.2.1 Application option 1: LPIS deals with classified (labelled) data related to wetlands and soil, normally in vector format

In this application option, the spatial data related to wetland/peatland comes primarily from the spatial interaction of two available data sets – (1) up-to-date wetland maps and (2) up-to-date or archive soil maps (**Figure 4**).

In the case of classified spatial data, the spatio-temporal aspect of the biophysical phenomenon located on/beneath Earth's surface (soil, wetness, vegetation) is modelled by a continuous set of geometric objects forming a discrete tessellation over a given area of interest. These objects have a geometry type being a polygon but could also be "realized" as clusters of pixels. The values of a given parameter or class assigned to the spatial object are derived mainly through semi-automated processes that involve domain expert interpretation, and are the same for each coordinate point within the spatial extent of the individual geometric object (delineation).

Figure 4. An example of LPIS reference parcel perimeter (in green for permanent grassland and yellow for arable land) overlaid on top of vector data of peat soils (class Tz – violet), peaty soils (class Tzg – brown) soils and N2000 wetlands (classes 7140 and 9080 - blue), with the national orthophoto as background. Polygons of peat and peaty soils located outside wetlands belong to the "Organic Drained" layer. Wetlands form part of the "Organic Wet" layer.

(a) (b)

Source: GTCAP

The spatial data on wetlands mostly comes from dedicated inventories of natural areas and ecosystems designated for protection. For that reason, one can assume that these refer to non-agricultural areas, due to the related natural constraints and restrictions applied in terms of potential land use. Moreover, the boundaries outlining the wetlands could have a legal and regulatory character, laid down in dedicated protection conventions or networks (Ramsar[3], N2000, national protection plans). The cartographic scale of the national datasets is usually coarser than the one applied for the LPIS (1:5000) and ranges from 1:10 000 to 1:50 000.

The spatial data on soils traditionally comes from morphological observations on the field to classify soil profiles into predefined classification systems. The surveyors extrapolate these classified soils to make a map supported by aerial photographs and other mapping sources, such as topographic maps, geostatistical methods for interpolation, and their own experience (Zare et. al., 2018). In this case, the basic geometric objects of discrete tessellation of Earth's surface are the soil mapping units. Although the delimitation could be based on physical elements of the landscape (ridges, gullies, rivers, vegetation), soil unit boundaries do not necessarily correspond to features visible on the terrain. This is also due to the diffuse nature of the boundaries between the neighbouring topsoil horizons and mostly because the historical human intervention has completely removed the natural relationship between soil and land cover. The mapping scale of the soil datasets is also coarser than the one used in LPIS. The cartographic scale of the national datasets usually ranges from 1:10 000 to 1:400 000.

Soil data alone could provide the necessary information on the location of organic soils, originating from peatland and wetlands (whether waterlogged or drained), if those data are up-to-date and comprehensive. However, traditional soil maps are seldom recent and often cover only specific land use categories (agricultural areas and forests). Given the purpose, product specification, and more efficient update through Earth Observation (EO) data of wetlands maps, these could provide some further evidence of the soil wetness and origin, through the vegetation type and its spatial composition visible on the surface. The intersection between the soil and wetland data could provide the candidate areas occupied by organic soils that are wet and organic soils that are drained.

Both for wetland and soil datasets, a prior semantic assessment of their classes could be made to develop the appropriate photo-interpretation key to be used on available LPIS reference orthoimagery.

There are two main decision paths in the ruleset. They deal with:

1. an LPIS reference parcel containing areas mapped as wetlands, part of the spatial layer "Organic Wet",
2. an LPIS reference parcel containing areas related to: 1) wet organic soils, part of the spatial layer "Organic Wet" and/or 2) the drained organic soils, part of the spatial layer "Organic Drained".

3.2.1.1 Spatial layer "Organic wet":

The layer is derived from the spatial union of (1) all mapped wetlands having a peat layer, and (2) all organic soil classes that are predominantly wet.

1. <u>Mapped wetlands:</u> The nature of the land cover types for wetland mapping products and the associated data capturing methodology implies that these have distinct observable characteristics of a bio-physical nature. Regardless of the wetland product specification and the adopted mapping scale, these areas will be well depictable in the reference orthoimagery used for the LPIS update and mappable in line with the LPIS cartographic standard.

   There should be further consideration for those wetlands with boundaries established in accordance with specific legislative requirements, due to the designated character of these areas (for example, Ramsar, N2000, national protection law, etc.). Such datasets fall largely within the scope of the INSPIRE Data Specification on Area Management/Restriction/Regulation Zones and Reporting Units (Tóth, K., Milenov, P, 2020). In such case, the interaction between the reference parcel and the wetland boundaries should be treated according to the principles laid down in the section "Interaction of spatial datasets with different specifications" of the Technical Guidance for Management of Layers in LPIS (Luketic et al., 2015).

   Processing thread 1: In the majority of cases, mapped wetlands with a peat layer in a natural state do not overlap with the agricultural areas mapped in the LPIS. In those cases, where such wetland areas intersect with the existing reference parcels, the properties of these reference

[3] Ramsar Convention on Wetlands: an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

parcels (perimeters, area, and exclusions) should be checked and updated where needed, using the up-to-date orthoimagery, in combination with the historical orthoimage archive.

Processing thread 2: Mapped wetlands with a peat layer that are already under agricultural management have their naturally occurred vegetation removed. The vegetation present corresponds to that typical of the applied agricultural management. Reference parcels intersecting such wetlands will be processed in accordance with the processing thread of the correspondent agricultural land cover type (processing threads 3 and 4). Before that, these reference parcels undergo processing thread 2, in which, the relevant complementary spatial information on the soil type, wetness status, and vegetation type, is made easily retrievable whether as an additional dataset in the LPIS or accessible through web feature services, to allow a verification on whether the soil and hydrologic conditions of the original peatland are largely unaltered. This will be key information for the subsequent assessment of the peatland wetness and its evolution.

2. Wet organic soils (not covered by the mapped wetlands with peat layer): Here, the scope comprises organic soils that have low and very poor drainage, and therefore are saturated during almost or part of the year. The nature of these soils and their environment implies that the areas in scope should have distinct observable characteristics of bio-physical nature. However, since these areas were not mapped in the wetland data, they likely have been converted to agricultural areas, thus being already part of the potentially eligible land in the LPIS and exhibiting characteristics and behaviour typical for the agricultural land cover. There are several options here, depending on the observable characteristics and the type of land recorded for the reference parcel:

   a) **Bio-physical characteristics typical for a particular natural wetland type**: Although not being mapped as wetlands, these areas still show bio-physical characteristics, typical for a particular wetland type -> they are identified as unmapped wetlands and processed following the approach given in **processing thread 1.**

   b) **Processing thread 3: Bio-physical characteristics typical of permanent grassland**: These areas show bio-physical characteristics typical of permanent grassland and are included in the set of reference parcels (or sub-parcels) recorded as PG in the LPIS -> A visual check could be done on up-to-date and historic orthoimagery to confirm the reference parcel (RP) agricultural land cover type as being permanent grassland. Large-size reference parcels, partly occupied with wet organic soils, could be further optimized (sub-divided) if stable internal boundaries (real world features, margins between natural and managed grasses) are found. The reason for this subdivision would be to isolate into individual spatial units, those areas that are clearly not affected by wet organic soils and are not subject to GAEC 2. This will facilitate the aid application process, increase the efficiency of the administrative cross-checks and any subsequent monitoring (**Figure 4**, b). The system should ensure that the relevant complementary spatial information on the soil type, wetness status, and vegetation type, should be made easily retrievable for the reference parcels in question, whether as an additional dataset in LPIS or accessible through web feature services. For wet organic soils, relevant intra-parcel variation in class labels or attribute values, which relates to characteristics that are not manifested physically on the surface, could be aggregated into a set of statistical metrics (mean, median, standard deviation, interquartile range - IQR) and be stored as an attribute to the reference parcel. If the soil information explicitly indicates the presence of a peat layer beneath the surface, these parcels are flagged for further assessment and tracking of peat layer conditions.

   c) **Processing thread 4: Bio-physical characteristics typical for arable land or permanent crop:** These areas show bio-physical characteristics typical for arable land or permanent crop and form part of the reference parcels (or sub-parcels) recorded as AL or PC in the LPIS, respectively. A visual check could be done on up-to-date and historic orthoimagery to confirm whether the RP agricultural land cover type is arable land or a permanent crop. Large-size reference parcels, partly occupied with wet organic soils, could be further optimized (sub-divided) if stable internal boundaries (field margins, annual use, shrub crops from tree crops) are found. The reason for this subdivision would be to isolate into separate spatial units, areas that are clearly not affected by wet organic soils and are not subject to GAEC 2. This will facilitate the application process and increase the efficiency of the administrative cross-checks and the subsequent monitoring (**Figure 4**, b). The system should ensure that the relevant complementary information on the soil type, water inundation, and vegetation type, should be made easily retrievable for the reference parcels in scope, whether as an additional dataset in LPIS or accessible through web feature services. In addition, any intra-parcel variation in class labels or attribute values of the data on wet organic soils, that relates to characteristics that are not manifested physically on the surface, should be aggregated into a set of statistical metrics (mean, median, Standard Deviation - StDev, Interquartile range - IQR), and stored as an attribute to the reference parcel. If the soil information indicates the presence of a peat layer beneath the surface, these reference parcels are flagged for further assessment and tracking of peat layer conditions.

d) **Processing thread 5: Bio-physical characteristics typical for woodland, shrubland, or other associated land cover types:** These areas show bio-physical characteristics typical for woodland, shrubland, or other land cover types such as those belonging to the main non-agricultural categories, defined in table 4 of ETS Annex III (DS/CDP/2015/07-REV4 part D) and form part of reference parcels recorded as such in the LPIS -> A visual check could be done on up-to-date and historic orthoimagery to confirm that these areas are assigned correctly to the correspondent land cover type and account for the natural features present within, using the outcomes of the semantic assessment to derive the proper interpretation keys.

In the case of wet organic soils, the least frequently occurring processing threads is the **processing thread 3.**

3.2.1.2 Spatial layer “Organic drained”:

The input relates to all organic soils that are NOT considered wet and are situated outside the geographic extent of the wetlands with a peat layer.

Drained organic soils: Here, the scope comprises organic soils that are currently NOT saturated with water, although they could have been regularly inundated in the past. Thus, they are qualified as drained. Since these areas are currently not wet, they probably (although still possible) no longer share the bio-physical characteristics, common for wetlands and peatlands, and are not “manifested” as such. These areas are mostly converted to agricultural areas, and are already a part of the potentially eligible land in the LPIS. They exhibit characteristics and behaviour typical for the agricultural land cover.

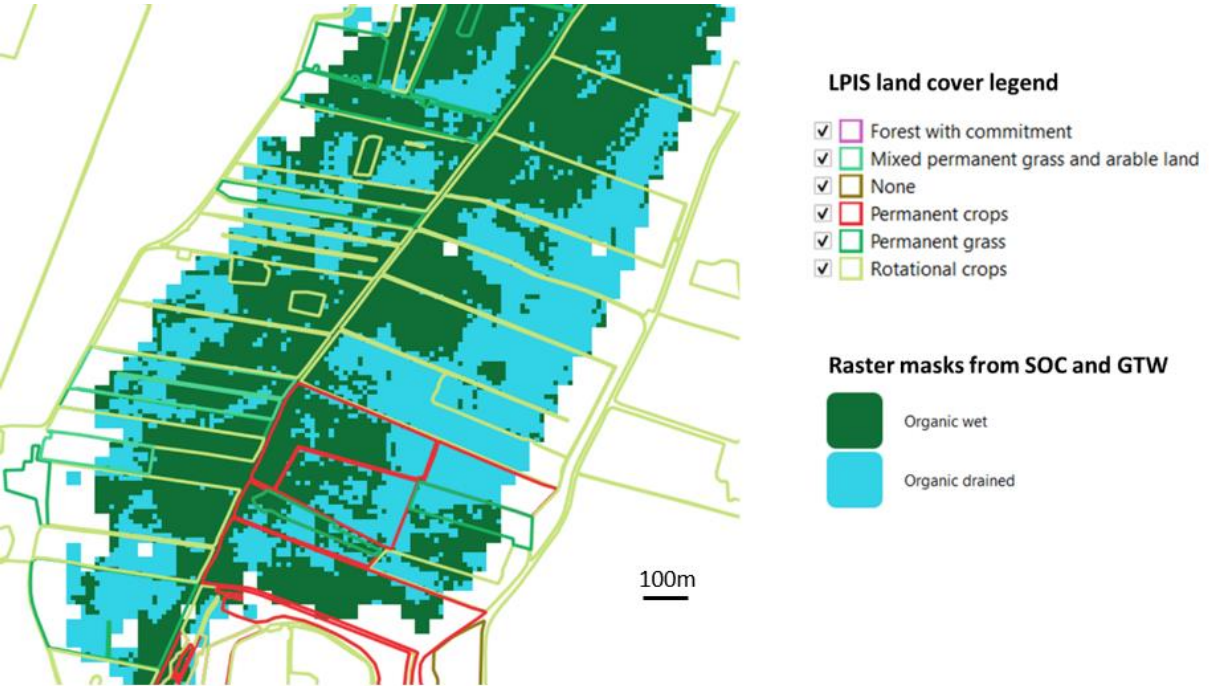
The decision workflow could follow the same logic as the one defined for wet organic soils. In practice, processing threads 3 and 4 will occur more frequently than processing threads 1 and 5.

3.2.2 Application option 2: LPIS deals mainly with continuous (measurement) data, largely provided in raster format

An alternative option to derive spatial data on wetlands and soil comes mainly from the spatial interactions of wall-to-wall raster datasets that provide continuous data for a given measurand; in this case, the Soil Organic Carbon (SOC) and Ground Water Table (GWT), as presented in SEPLA Deliverable 1 (Milenov, et al., 2022). Contrary to the discrete coverages having values only where they are defined, continuous coverages can be interpolated thereby providing intermediate values (ISO/DIS 19123-1, 3.1.15). SOC and GWT datasets are produced by different methods involving field (soil, plant, water depth) sampling, EO data, machine-learning and modelling to infer the soil and wetness characteristics over the entire area of interest. Each pixel of the raster file provides either SOC or GWT values with a known degree of probability. Where raster datasets are continuous, there is no discrete tessellation applied. Boundaries could be “simulated” by creating binary raster masks separating wet from drained, and organic from non-organic soils. The masks are generated by applying applicable thresholds on SOC and GWT datasets (**Figure 5**). The SOC thresholds usually are based on the national and/or FAO compliant definitions of organic soil (for example, a mask of organic soils could be generated by setting SOC values higher than 20%). A mask of the wetness could be produced by thresholding the original measurement data on GWT, using training samples from real minerotrophic peatlands and applying statistical metrics (e.g. quantile). These samples could come from the available wetland data, after verification of their actual presence or, alternatively, from other thematic datasets where such areas are mapped (peat maps from dedicated studies, soil inventories, maps of designated N2000 sites, etc.).

Although the threshold could be based on physical properties and robust methods, any masking is done on pixel values with an inherited degree of uncertainty (due to the interpolation models applied). Consequently, it conveys some of that uncertainty to the position of the resulting discrete boundaries. Also, for some peatland types, such as raised bogs, that receive water and nutrients through precipitation (ombrotrophic), SOC and GWT will not be sufficient as criteria, since bogs will most likely not appear as wet based on GWT thresholding. Alternatively, these peatlands could be captured by the SOC and GWT, complemented with raster data on soil pH, because of their acidic and low-nutrient environments. Their raster masks could be augmented with archive vector data on (mainly ombrotrophic) peatlands in protected designated areas.

Figure 5. An example of LPIS overlaid on top of raster data SOC and GTW, thresholded to produce masks of the spatial extent of Organic Wet and Organic Drained.



Source: GTCAP

As in application option 1 (section 3.2.1), there are two main decision paths in the ruleset. They deal with:

1. an LPIS reference parcel containing limited areas mapped as peatlands, part of the spatial layer “Organic Wet”,
2. an LPIS reference parcel containing areas related to: 1) SOC and GWT above certain thresholds (complemented with pH data below a certain threshold), part of the spatial layer “Organic Wet” and/or 2) the SOC within a certain threshold range and GWT below certain, part of the spatial layer “Organic Drained”.

3.2.2.1 Spatial layer “Organic wet”:

These rules apply where an LPIS reference parcel contains limited areas mapped as peatlands, part of the spatial layer “Organic Wet. The layer is derived from the intersection of the organic soil mask and the wetness mask (and possibly pH mask), complemented with any up-to-date vector maps of peatland part of protected areas.

1. Mapped peatlands in protected areas: The decision workflow is identical to the one used applicable for the mapped natural wetlands with peat layer in Application option 1 - processing thread 1 (Section 3.2.1.1).

2. Organic soil AND wetness mask: AND pH mask: The decision workflow follows the logic applied for Wet organic soils in Application option 1. In this case, however, processing thread 3 (Section 3.2.1.1) is expected to be the most frequently used.

3.2.2.2 Spatial layer "Organic drained":

This layer is derived from the part of the organic soil mask, that is not intersected by the wetness mask, and it is further clipped by any thematic data on ombrotrophic peatlands.

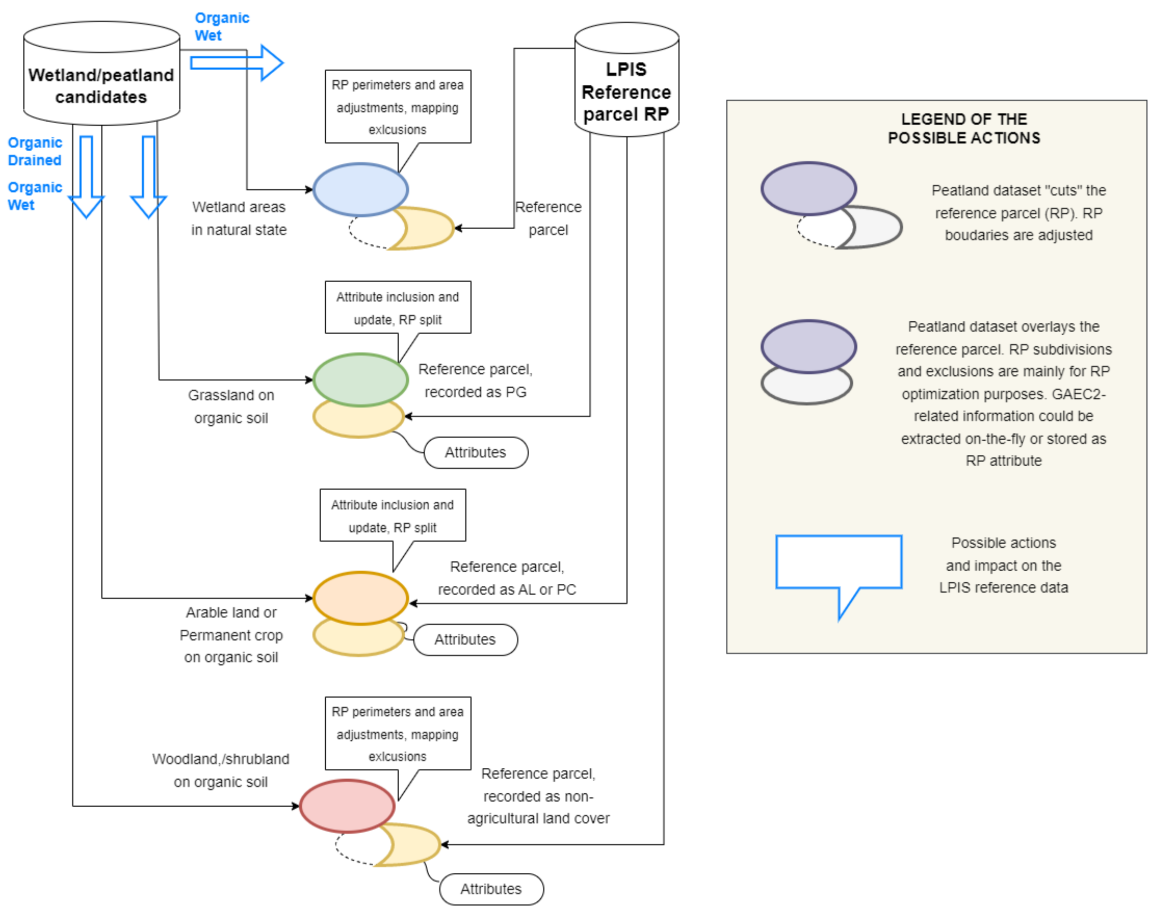
Drained organic soils: The decision workflow could follow the same logic as the one defined for drained organic soils in Application Option 1. In this case, however, processing thread 4 (Section 3.2.1.1) is expected to be the most numerous.

In general, for those reference parcels enclosing pixels from the different raster masks on Organic Wet and Organic Drained, the following approach is adopted:

1. If the change between the different masks is manifested in an observable boundary on the orthophoto associated with geographic features or agricultural land use, this boundary could be used for delimitation during the on-the-fly assessment or be considered as a candidate boundary to subdivide the reference parcel and create sub-parcels.
2. If no such evidence is present, the raster data is treated as a data signal (Devos et al., 2021) and aggregated into a set of statistical metrics (mean, median, standard deviation, IQR), and stored as an attribute to the reference parcel (see also the example in Table 1).

Figure 6 illustrates the interactions between the peatland-related data and the LPIS, depending on the above-mentioned processing threads.

Figure 6. Interactions between the peatland-related data and the LPIS, per processing thread, depending on the observable characteristics and the type of land cover recorded. NOTE: The diagram does not make a distinction between classified and measurement data.



Source: GTCAP

3.3 Implementation aspects of the LPIS "carbon theme"

There are several practical actions an IACS custodian needs to take when it comes to the integration of the "soil carbon information" in the LPIS:

1. To define the population of reference parcels affected by the spatial datasets on Organic Wet and Organic Drained, and being subject to the processing threads listed above.
2. To set the rules for assessing the significance of the "overlap" between the reference parcel perimeter and the spatial datasets on Organic Wet and Organic Drained, in order to identify those reference parcels, containing areas to be subject to the GAEC 2.
3. To find the most appropriate approach to ingest, record and display the GAEC 2-related information in the LPIS.
4. To agree with the farmer on the GAEC 2 status in the reference parcel, where agricultural parcels are declared.

Box 3. Stakeholder engagement

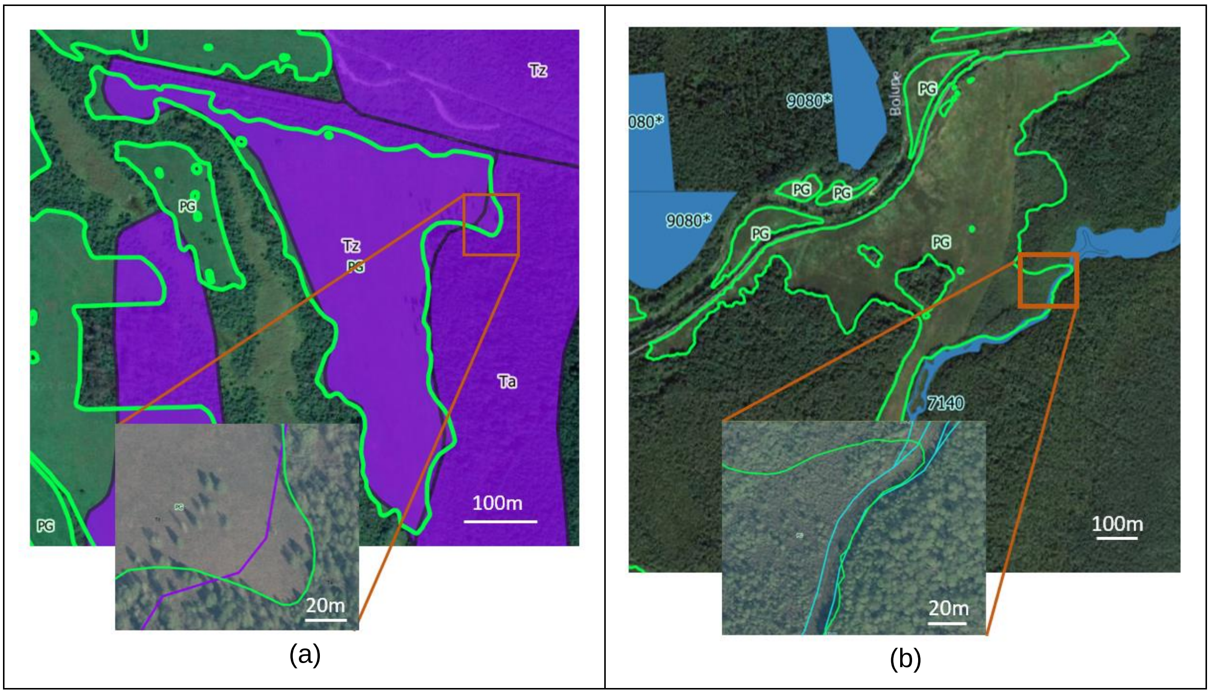
To keep the stakeholder community engaged and ensure the regular collection of relevant feedback, SEPLA project team has organized regular bilateral meetings with the Member State's technical experts involved in the SEPLA project. During these technical meetings, SEPLA team presented the intermediate results of the methodological development and the associated tests performed on the selected pilot sides, located in the four EU Member States involved. The technical viewpoints and recommendations received from the EU MS experts were documented. Those relevant to the elaboration of the IACS "carbon teams" are summarized and presented in this document.

3.3.1 Reference parcels affected by spatial datasets on Organic soils, originating from peatland

The population of "candidate" reference parcels subject to the GAEC 2 are those reference parcels, classified as arable land, permanent grassland and permanent crop, which intersect with the spatial data related to organic wet and organic drained (**Figure 1**). As evidenced above, this latter could be either labelled data in vector format or continuous measurement data in raster format.

The term "intersection" should be considered in a broader sense than the strict, mechanical "spatial intersection", which requires spatial overlap or adjacency between the reference parcel perimeter and the spatial objects of the peatland-related datasets. It should account also for cases where reference parcels are not touching but are close enough to the peatland spatial objects that they influence each other in the field. To locate where this broader sense applies, one should consider the cartographic scales and product specifications involved. The assessment of proximity could be performed through the application of a buffer around the RP perimeter. Marginal overlaps should not be automatically discarded, because they could refer to specific geographic features (**Figure 7**, b). More information on the cartographic scale and mapping accuracies is given in section 4.

Figure 7. Two examples of handling intersections between the LPIS reference parcels and (a) peat soil and (b) wetland data. In example (a) there are two soil units with different peat soil types intersecting the reference parcel. The 0,15ha overlap of the soil unit with class Ta could be disregarded, as it is below the minimum mapping unit of the soil map (0,25ha-0,30ha). In example (b) however, the 0,2ha overlap with the wetland (N2000 class 7140 - Transition mires and quaking bogs) relates to a narrow creek visible on the national orthophoto, which is hydrologically connected eastwards with a bigger peatland (probably fen).



Source: GTCAP

3.3.2 Dealing with reference parcels partially covered by organic soils

A reference parcel that is fully within the spatial extent of the GAEC 2-related datasets is very likely subject to the GAEC 2 and needs no further processing. A reference parcel can also partially overlap the spatial extent of these datasets. There can be two cases here:

1. The reference parcel partially overlaps with the spatial objects of the datasets related to the GAEC 2.
2. The reference parcel encloses complete spatial objects of the datasets related to the GAEC

The sets of rules for assessing the “overlap significance” largely depend on: (1) the nature and specifications of the datasets related to the GAEC 2 (vector/raster) and (2) policy ambitions set at the national level. These rules are also influenced by the choice of the modality (spatially explicit, alphanumerical, on-the-fly) to handle the relevant spatial data on organic soil and wetness status at the level of the LPIS reference parcel. That modality depends on the specific LPIS design and update cycle. There should be a practical solution on how to deal with reference parcels that have a mix of mineral and organic soils or where the organic layer will partially intersect the geometry of the reference parcel. Due to the nature of the soil and specific drainage conditions, the boundaries of the peat layer will be rather fuzzy and gradual; it is difficult to properly delineate such boundaries in the LPIS. There is also the challenge of how to manage the dataset updates related to changes caused by physical land changes and/or triggered by using newer data capturing methods. The peatland mapping is expected to improve gradually over the coming years, through the adoption of new tools and technologies, as well as through iterative consultation with the farmer. The technical overlaps with the LULUCF (issues of drained peat soils) and future Nature Restoration Law (peatland rewetting) need to be considered as well.

3.3.3 Modalities for implementing the IACS "carbon theme" in the LPIS

Some of the EU Member State's experts involved in SEPLA find the introduction of an additional attribute at the reference parcel level, indicating whether the given reference parcel is subject to the GAEC 2 requirement, as a simple and practical solution; especially in those cases where the parcel is partially covered by the GAEC 2 extent. Having an upfront verdict for the applicability of the GAEC 2 over the entire area of these reference parcels will remove the need for the farmer to deal with complex and potentially imprecise information during the GSA application. The data on organic soil, being coarser and diffused in terms of spatial delimitation (even sometimes obsolete), might create issues and disputes during the application process. This practical approach, certainly, doesn't exclude the need to consult the farmer prior to the decision to place the given reference parcel within the GAEC 2 scope, but setting the GAEC 2 verdict upfront will decrease the administrative burden during later stages, e.g. in the application process for the CAP subsidies. The foreseen flag will simply report for the presence of organic soil beyond a certain threshold (for example when more than a certain percentage of the reference parcel area is occupied by organic soil) and will not store specific data on the respective area share. More details on the possible options to handle the information alphanumerically are given in section 3.3.6.

Another group of experts from the EU Member States expressed the view that the direct incorporation of specific "soil carbon"-related information in the LPIS core datasets, such as the flag at reference parcel level or through mapping, would not be optimal, especially in the case of dynamic land management. They consider that the purpose of the reference parcels should be to delimit the stable (and visible) boundaries and the overall land eligibility and should not directly handle information about specific schemes or conditionality requirements. Such information should be kept in separate layers within or external to the LPIS/GIS system. The goal for reference parcels is that they should stay stable in time. The more scheme-specific information incorporated in the reference parcel, the more complex the management and update will be. This could hamper the stability and robustness of the reference parcel's elements (geometry, attribute) and might increase the risk of errors affecting area values. EU Member States could have a very strict rule on keeping the core reference LPIS layers (RP geometry, exclusions) up to date and tight deadlines for the inclusion of any new information, considered of relevance to them.

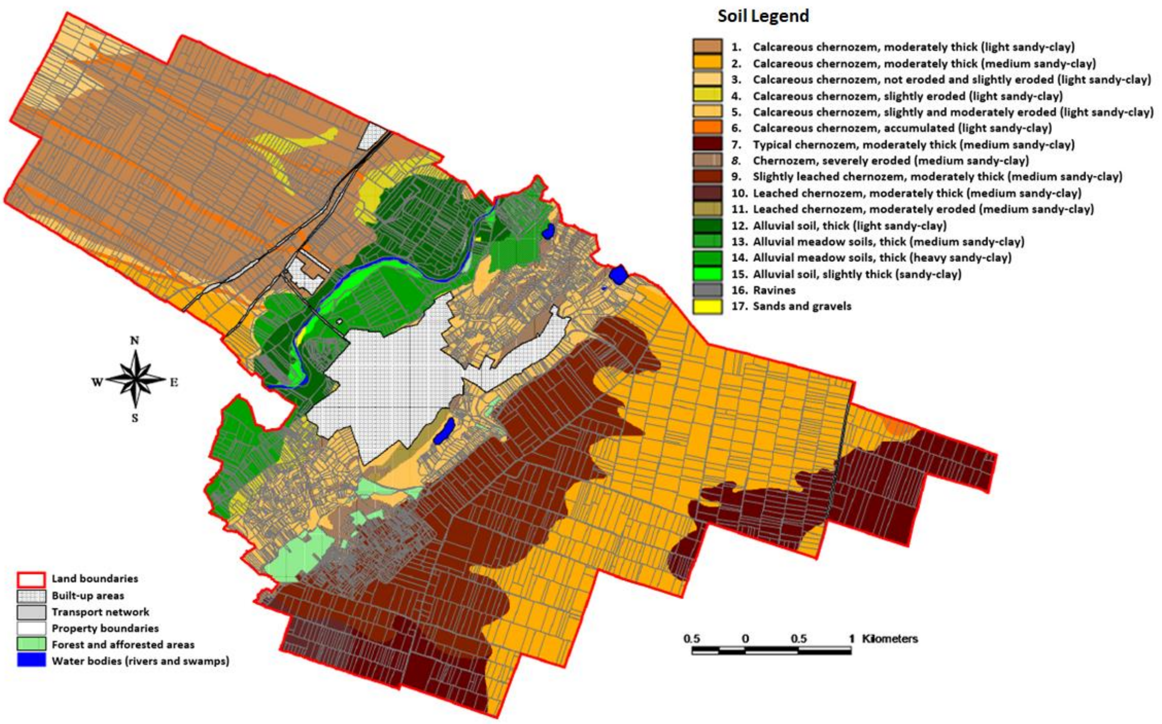
In this approach, it is important to distinguish between the need to have information: 1) in the overall LPIS/GIS system, which can then be used for e.g. overlap analysis with the reference parcels and 2) on the core properties and attributes of the reference parcel. The more information is directly embedded in the reference parcel object, the more the need for updates to meet the different purposes. Such a process will lead to a drift of the reference parcels from their original (direct payment-related) purpose.

Where these considerations apply, they offer arguments for keeping soil and wetness-related data in a separate dataset(s) and generating a verdict on the applicability of GAEC 2 over a given reference parcel on the fly. Such additional datasets could be ingested in the GSAA and made visible to the farmer, during the declaration process, to guide the application for the CAP payments.

3.3.4 Consultation with the farmers

It was the EU MS experts' view that irrespective of the above MS choice on handling GAEC 2 data in LPIS, a decision on whether a reference parcel or part of its area is subject to GAEC 2, should be done in closer consultation with the farmer. This process should consider the uncertainty around the peat-related boundaries, and the farmer's technical capacity to account for this in the agronomic practices he/she applies. Farmers and administrations in the EU Member States have experience in dealing with large-scale soil maps in the context of precision farming and there are GNSS-enabled technological solutions that allow the farmers to apply tailored inputs in different parts of their agricultural parcels (**Figure 8**).

Figure 8. Agricultural parcel data, integrated with a soil map (1:10000) for the purpose of precision farming and for the suitability assessment for specific crop production. Data on soil is not aggregated at the agricultural parcel level. Soil boundaries are considered detailed enough and are ingested as a basis for the GNSS tracks that the agricultural machine could follow.



Source: Agricultural Academy, Institute of Soil Science, Agrotechnology and Plant Protection "Nikola Poushkarov", Bulgaria (translated)

3.3.5 Remote sensing-based aids

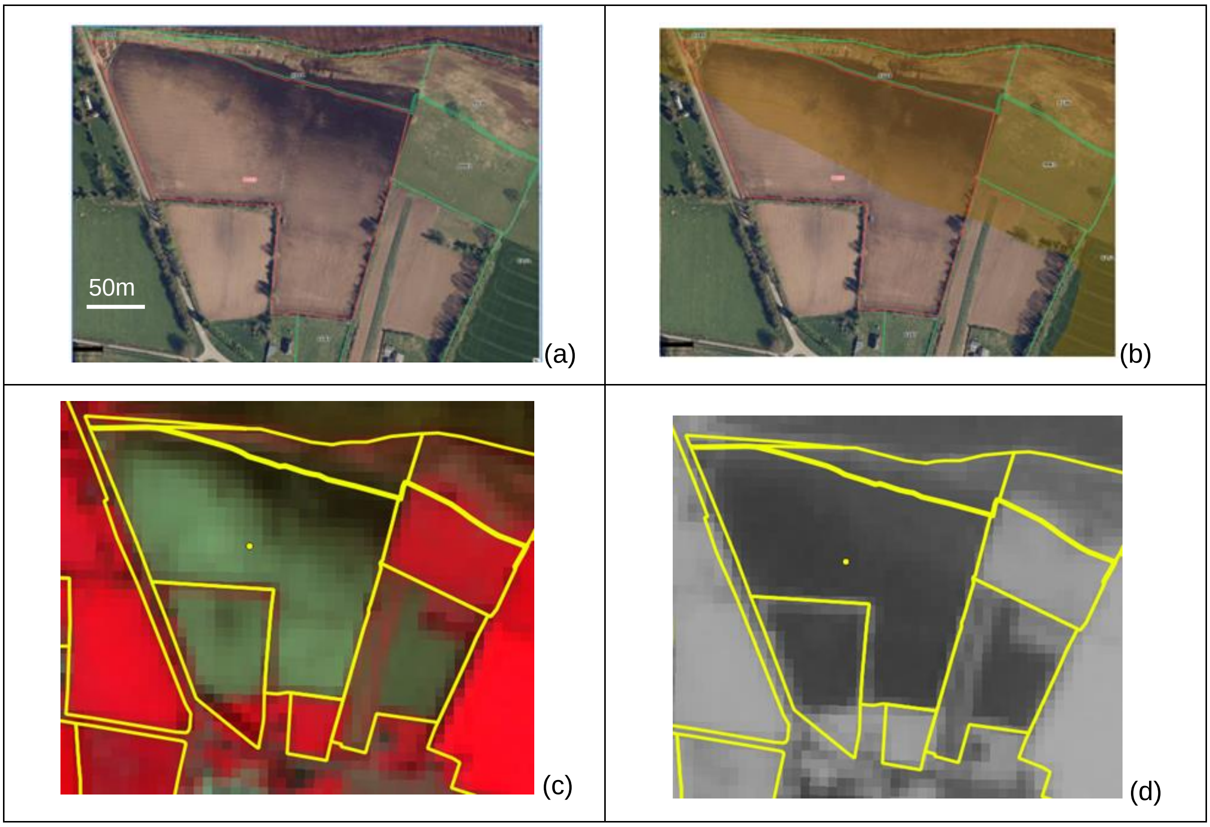
There is a consensus among all involved experts that when soil data from historical soil surveys is used for the location and subsequent delimitation of the GAEC 2 areas, that data set should be complemented by a procedure to identify peat areas visible on and captured from satellite or aerial orthoimagery. This avoids farmer objections and the need for additional soil sampling.

The type of remote sensing method varies depending on the available technology and expert capacity and could include, for example, satellite-based criteria, such as:

- monitoring of the surface's vertical displacement, looking for a notable seasonal variation which could confirm the presence of the peat beneath,
- assessing the phenology behaviour of the vegetation using time series analysis of dedicated vegetation indices or reflectance properties (applicable for grasslands),
- assessing the surface properties (colour, roughness) in the periods when the arable land is not covered by vegetation (applicable for arable land).

Even obsolete and possibly incompatible, legacy soil classifications can provide insights about the soil genesis and the (im)precision of the peat layer boundaries at the reference parcel level. This information could be helpful when assessing the data captured through EO-metrics/markers. For example, there could be cases where in alluvial areas (and in the vicinity of deep ditches), a peat layer is located at a certain depth under a layer of mineral soil. In such cases, if ploughing alters the mineral horizon only, these areas might not be considered subject to GAEC 2, even if the underlying peat layer has a substantial thickness (above 40 cm). Depth to peat is not considered a parameter in the current SEPLA semantic meta model but should be included in a revision to allow a better description of the characteristics of the given land phenomenon. The coverage of the peat layer by a mineral topsoil horizon should manifest differently compared to the topsoil peat horizon, as visible in **Figure 9**.

Figure 9. (a) A reference parcel (in red) with managed grassland, just before sowing, when bare soil is visible. The darker areas in its Northern part are associated with peat soils (b) the same reference parcel with the layer of peat soils shown in light brown. (c) the same reference parcel is shown on Sentinel-2 false colour near-infrared image from the same period, with the peat areas clearly visible. (d) the same reference parcel overlayed with NDVI derived from the same Sentinel-2 image where peat areas are less visible. This shows the limitations of the NDVI index to depict bare soil differences. Other indices, such as BSI and NDWI, and additional bands, such as thermal IR, could be more appropriate.



Source: GTCAP

The presence of peat, evidenced by the soil map, could be confirmed also through the type of vegetation present on the surface and its behaviour (ex. Sphagnum mosses are mostly present on bogs). Such relation (vegetation-soil) was already evident from the semantic assessment performed on the soil classes for the EU Member States, participating in the SEPLA project. The vegetation behaviour and its possible relation to soil could be assessed through multitemporal analysis of Copernicus Sentinel data and using object-oriented approach (**Figure 10**). It will result in clusters of pixels with a sufficient dimension to depict individual features in the range of 0,2ha (Milenov, Vajsova et. al., 2021).

This could include further technical development related to the use of InSAR to track seasonal vertical motion displacements, typical for some peatlands, such as the raised bog. The archive of the European Ground Motion Service (EGMS) is already available for download from mid-October 2022. This is an important technical development also for the purpose of peatland monitoring.

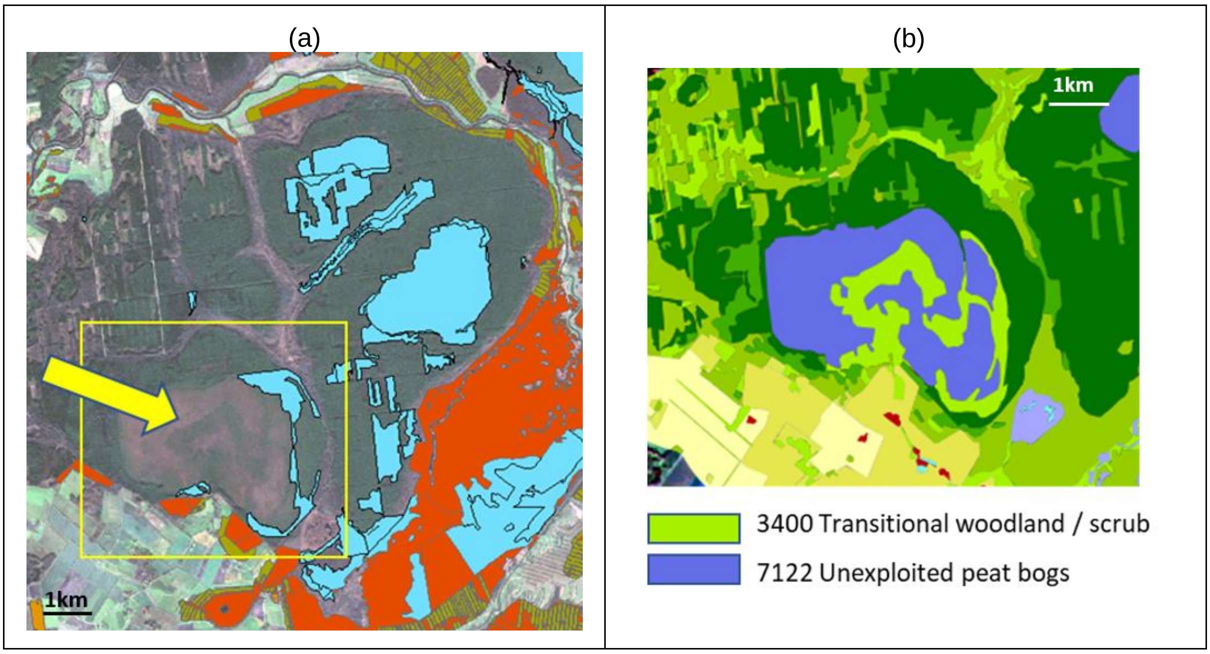
Figure 10. (a) Reference parcel with permanent grassland (solid green line) partially overlapped with peat soil (dashed brown line) on reference orthophoto. (b) same reference parcel on a cluster map generated from multitemporal segmentation of Sentinel-2 data. The darker the green, the higher the amplitude of vegetation dynamics. The very dark green areas that correspond to peat soil have a distinctively higher amplitude (in this extract, above the 8th decile point of the amplitude histogram, calculated from the pre-defined region of interest) than the rest, probably due to the higher water retention capacity of the peat (also confirmed by the high ground water table of the local GWT model).

Source: GTCAP

Obviously, it will be difficult to assess the ground situation on reference parcels with permanent crops or short rotation coppice, found subject to the GAEC, due to the visual obstruction caused by tree canopies. In such cases, the presence of peat-related characteristics could be verified through geotagged photos.

Datasets from the Copernicus Land Monitoring Service (CLMS) operated by the European Environmental Agency (EEA) could provide ancillary support in cases of obvious disagreements or gaps between the local datasets and the LPIS, because these services provide an alternative view of the situation based on the (same) EO data (**Figure 11**).

Figure 11. (a) Missing peatland in the national wetland dataset. (b) Missed peatland mapped in the Copernicus N2K product of EEA.



Source: GTCAP

Apart from the thematic datasets, CLMS could also provide reference data, such as a digital elevation model (DEM), which in combination with local datasets, could provide insights into the topography of the peatland types found on specific landforms (for example, blanket bogs develop on undulating terrain).

3.3.6 Bringing GAEC 2 in the LPIS “reference layers”

It can be concluded that the realization of the “IACS carbon theme” will involve interaction between the LPIS reference layers and the GAEC 2-related datasets. It will be up to the EU Member States to decide whether this interaction will be conducted on-the-fly or through an introduction of certain GAEC 2 – related data and information in the LPIS reference layers. A combination of both operations would be also possible.

Those EU Member States that find it necessary to explicitly capture and store the soil and wetness information in the reference data of the LPIS, have two modalities:

3.3.6.1 Spatially explicit

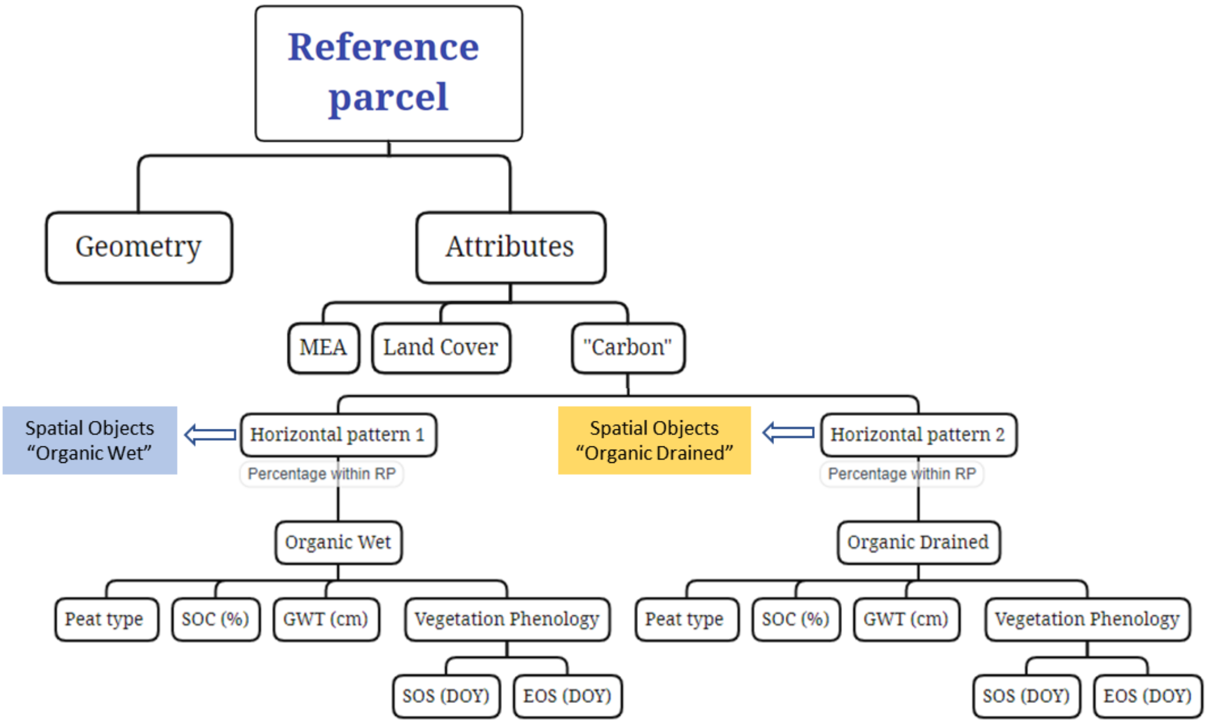
This option is applicable when there is observable physical evidence on the surface that could be used for the delimitation or the confirmation of a candidate internal boundary (compatible with the LPIS cartographic standard): (1) structural-physiognomic – geographic features, visible and stable limits between different land cover/land use; (2) phenological – distinct temporal profiles of the vegetation over the candidate areas/clusters within the reference parcel. Such internal delimitation could either affect the RP geometry, resulting in smaller reference parcels or can be stored in a separate thematic dataset.

3.3.6.2 Alphanumeric

This option is applicable when there is no physical evidence on the surface that could be reliably used as a boundary for mapping. This will be the more widely used option. In this case, the information could be stored at the level of the reference parcel as a single attribute (as explained in Section 3.3.3) or as a set of attributes. The set could be useful when dealing with classified data or measurement data with notable intra-parcel differences that cannot be aggregated and reflected accurately by statistical metrics (mean, median, StDev) **Figure 12** represents a possible set of hierarchically structured attributes reflecting soil and wetness characteristics organized into Organic Wet and Organic Drained categories with their respective area shares. The spatial distribution and proportion of both categories are recorded in the element “horizontal pattern”. The proposed structure is based on the ontology of the Land Cover Meta Language – LCML (ISO 19144-2). It has the following storage elements:

- Horizontal pattern – the percentage of the reference parcel area, occupied by the given category,
- Peat type – the peatland type, according to a local pre-defined code list,
- SOC – the value (statistical metric) of Soil Organic Carbon in percentage,
- GTW – the value (statistical metric) of the Ground Water Table in centimetres,
- Vegetation Phenology –optional key phenology parameters of the associated vegetation, such as Start-Of-Season and End-Of-Season, measured in Day-Of-Year (mostly applicable for natural grasslands).

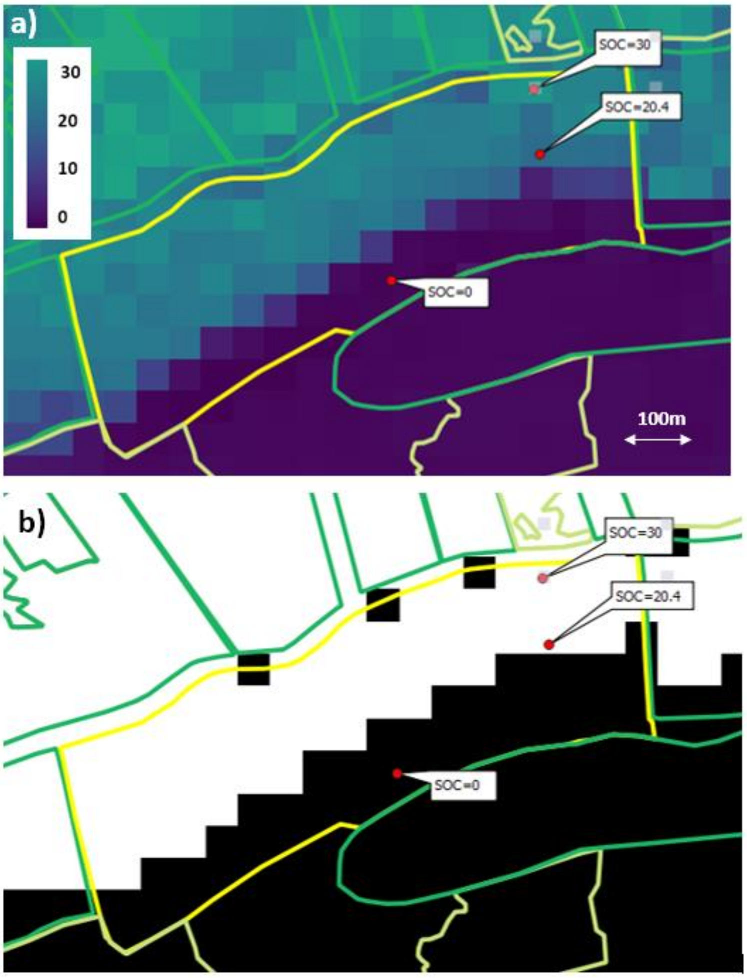
Figure 12. A possible set of hierarchically structured attributes reflecting soil and wetness characteristics at the level of the reference parcel, based on the Land Cover Meta Language – LCML. Each of the "horizontal patterns" will be logically associated with the relevant spatial object in the GAEC-related dataset, related to the "Organic Wet" and/or "Organic Drained" categories.



Source: GTCAP

Figure 13 illustrates the changing values of Soil Organic Content within a reference parcel and the corresponding binary mask where values of SOC larger than 20% (assumed SOC threshold value indicating organic soil) are marked in white. **Table 1** summarises several statistical metrics of the real SOC values depicted in **Figure *13***. The most accurate approach to characterise such parcels, covering both mineral and organic soils, would be using 2 different horizontal patterns and relevant sets of attributes. If such approach is not favoured and only one single attribute (set of attributes) for entire parcel needs to be derived, attention should be put on the choice of an optimal statistical descriptor(s). Although, in the example shown, majority (66%) of the reference parcel area is covered by organic soil (SOC above 20%) the mean value of SOC within the parcel polygon is equal to 16,4% (and thus indicating organic-rich or even mineral soil, depending on the local definitions). Therefore, the median value of SOC data within the reference parcel, equal to 21,8% in the example below, could be considered as more representative. Usage of other statistical descriptors could help to further characterise the intra-parcel data distribution.

Figure 13. An example of a) changing SOC values within a reference parcel (outlined in yellow) and b) the corresponding binary SOC map where values larger than 20% are marked in white. Table 1 provides several statistical descriptors of the SOC values within the reference parcel.



Source: GTCAP

Table 1. Statistical descriptors of the SOC values within the reference parcel are presented in **Figure *13***.

Pixel count	Mean	Median	Standard deviation	Minimum	Maximum	q75
106	16,4%	21,8%	10,5%	0,1%	30,3%	26,0%

Source: GTCAP

4 Specific technical aspects

Certain good practices described in the Technical Guidance for the Management of layers in LPIS (Luketic et al., 2015) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories are complemented here, wherever needed, with some particular details relevant to the elaboration of the IACS "carbon theme".

4.1 Units, precisions and coordinate reference systems

The LPIS has a 1:5000 map scale with hectares as an area unit. The land declarations made by farmers need to be recorded with a precision of 0.01ha. As a rule of thumb, to exclude rounding issues, calculations should be done with a 2 digit higher decimal precision than the value recorded in the system. For this reason, it is recommended to express all area values in the system, derived from the integration with spatial data related to Organic Wet and Organic Drained, in square meters with at least 2 decimal places, or hectares with 6 decimal places. All lengths and distances should be expressed in meters with 2 decimal places (Luketic et al., 2015).

The LPIS operates in the national coordinate reference system, usually created by a national mapping agency. The coordinate reference system is defined by a geodetic datum (a reference to the earth's globe) and a coordinate projection system that defines the transformation of the idealised globe to the 2-dimensional map plane. All data related to Organic Wet and Organic Drained should either be in the national coordinate reference system or if not, the relevant on-the-fly transformations should be applied.

4.2 Spatial resolution, accuracy and error propagation

Digital geospatial data are an abstraction and an approximation of reality. They digitally model the real world to represent its aspects/characteristics captured with an acceptable degree of inherent uncertainty. The process of converting the continuous values characterising any real-world phenomenon into the discrete set of values used by the computer systems (quantization), is inevitably linked with some data/information loss, causing additional, mostly small, inaccuracies. Operating the information systems with a higher numerical level of detail (than the one used for administrative checks and reporting) may mitigate the impact of approximation and discretization (Luketic et al., 2015).

In the case of the LPIS, its accuracy should be at least equivalent to that of cartography at a scale of 1: 5.000. This can be specified via horizontal absolute positional accuracy expressed as a maximum RMSE of 1,25m. To achieve this, any content should be based on and updated using orthoimagery with a ground sampling distance below 0,5m. This allows a reliable depiction and mapping of individual geographic features of 0,03ha and larger (and even down to 0,01ha in the spatial resolution of the reference orthoimagery allows) without the risk of exaggerating their area or misplacing their boundaries.

When creating the "IACS carbon theme" a variety of different data sources and approaches will be used. The soil maps or modelled soil organic content maps may be represented in smaller scales, i.e., 1:20.000 to 1: 100.000 and thus are less accurate and use a larger minimal mapping unit (MMU). The geographic explicit forest inventories for the LULUCF apply the minimal mapping unit of 0,2 ha, which could be proposed as an indicative value for the minimum mapping unit of the "IACS carbon theme". It also corresponds to the maximum size of the feature whose nature could be identified on Sentinel-2 imagery. To correctly map a feature using Sentine-2 data, its size should be at least 0,35ha (35 times the pixel size of the visible bands). However, EU Member States are free to define different MMU, as suitable for local data quality and reliability.

The lower spatial quality of datasets to be integrated with LPIS data will certainly affect the results of the integration. Error propagation could result in a lower quality than the worst of the two (even when each of the two separately is a consistent product). Therefore, a careful analysis should be carried out in advance to assess to what extent the datasets can be integrated and what the impact on the final product will be. The internal and external quality assessment reports for both the classified and measurement datasets should provide the necessary information.

Quality checks of modelled data, based on ground samples, e.g. the SOC data, if performed, are usually reported in terms of the reliability of the model predictions at certain discrete locations (check points). In cases where the specific data isolines should be used as a class border, it would be more helpful to get estimates of the absolute positional accuracy of the considered SOC isolines, e.g. for the border value of 20%.

4.3 Spatial interaction between the layers in LPIS

To assure the required level of accuracy all data, explicit datasets and maps resulting from modelling or image classification should be harmonized. Harmonization doesn't necessarily imply that all data must have the same accuracy level but ensures that the combined and resulting information meets the minimum requirement. The representation of a real feature in different map scales may look different due to shape generalization. Nonetheless, consistency between the datasets should be ensured. The semantic relationship between the thematic information stored in the third-party spatial dataset (i.e. wetland map, protected areas, and national land cover information) and the LPIS, needs to be assessed prior to any integration.

The following good practices should be adhered to when combining different data types and sources (based on IPCC, 2019) in order to ensure results with the required quality:

- The metadata of the data sources, and especially the spatial scales, creation dates and the minimal mapping unit should be documented;
- The consistency between the spatial scales of the source datasets should be ensured;
- The conformity of the spatial datasets to national mapping standards should be checked. Any notable deviation, especially with reference to the legacy/historical data, should be documented;
- A hierarchy among various data sources should be established before the process (higher quality data prevail where an inconsistency with other data appears);
- Any uncertainties in the data integration should be documented.

5 Conclusions

This report aims to provide some good practices on the methods and tools the Member State Administrations could use in support of the creation of the "IACS carbon theme". It builds upon the work on the methodology for identification and mapping of candidate peatlands and wetlands areas for the LULUCF, the experience of creating and managing LPIS and the collective and continuous feedback provided by the Member State's technical experts involved in the SEPLA project.

One assumes that the introduction of the GAEC 2 information in the LPIS should be performed in the most efficient and effective way possible, with minimal changes to the LPIS design and its update process. Nonetheless, to attain the GAEC 2 objective and allow for informed management choices, information on the drainage and wetness status should be stored, if possible, together with information on the soil characteristics. It is the view of the EU Member State experts that the formal mapping requirement for LPIS in the new CAP remains as before; any introduction of spatial information in the core datasets of the LPIS (reference parcel, land cover, exclusion areas, etc.) should be related to physical evidence of geographic features or phenomena present in the field. The GAEC 2 requires the LPIS to interact with other spatial datasets, such as soil and wetness, which are different in nature and specifications from the data that LPIS typically deals with. The features and phenomena reflected in these datasets do not often have explicit physical manifestations and their spatial extent is much fuzzier. For that reason, the spatial data used as a basis for the location and delimitation of the GAEC 2 areas, should be complemented by the EO-based criteria indicating and confirming the actual presence of those areas.

Whatever methods and tools are applied to integrate the GAEC 2 information in the LPIS, EU MS experts believe that the final outcomes should be based on a documented bilateral agreement reached with the farmers. Such public consultation to bring in the farmer's experience could be implemented within the LPIS update and upgrade cycle. Stakeholder involvement is also important for the upcoming carbon farming initiative and the introduction of alternative farming practices on peatlands, such as paludiculture. An exchange of information and know-how between EU Member States on these processes will be extremely beneficial and should be encouraged.

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List of abbreviations and definitions

CAP	Common Agricultural Policy
CbM	Checks by Monitoring
CLMS	Copernicus Land Monitoring Services
EEA	European Environmental Agency
DEM	Digital Elevation Model
EC	European Commission
EO	Earth Observation
EU	European Union
GAEC	(Standards for) Good agricultural and environmental condition of land
GHG	Green House Gases
GSAA	Geospatial Aid Application
GTCAP	Guidance and Tools for CAP
GWT	Ground water table level
IACS	Integrated Administration and Control System
IPCC	Intergovernmental Panel on Climate Change
JRC	Directorate-General Joint Research Centre of the European Commission
LCML	Land Cover Meta Language
LPIS	Land parcel Identification System
LULUCF	Land use, land-use change and forestry
LUML	Land Use Meta Language
MMU	Minimum Mapping Unit
MS	Member State
PA	Paying Agency
RMSE	Root Mean Square Error
RS	Remote Sensing
RP	Reference Parcel
SEPLA	Satellite based mapping and monitoring of European peatland and wetland for LULUCF and agriculture
SOC	Soil organic carbon content
UML	Unified Modelling Language

alluvial: deposited by surface water

anaerobic: conditions where oxygen consumption by soil biota exceeds the diffusion of oxygen into the soil profile; anaerobic soils have restricted flow of air within pores, owing to a high moisture or water table level

hydrophytic: adapted to growing in aquatic (e.g. prolonged saturation or flooding) and the low-oxygen (anaerobic) conditions

inundation: the state of being submerged, flooded, inundated

measurand: a quantity or property intended to be measured minerotrophic: refers to environments that receive nutrients primarily through groundwater that flows through mineral-rich soils or rock, or surface water flowing over land. Lower acidity and higher nutrient availability allow more plant diversity (e.g. mosses, sedges, woody shrubs)

morphological: observation of the size, shape and structure of an object

ombrotrophic: refers to environments that receive all of their water and nutrients from precipitation. Organisms tolerant of acidic and low-nutrient environments prevail and peat is often dominated by Sphagnum mosses

perturbation: alteration, change of state of a function

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