D2.1 Literature review and existing models report

***MAIL**: Identifying Marginal Lands in Europe and strengthening their contribution potentialities in a CO2 sequestration strategy*

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[1] **R** = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other

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ABBREVIATIONS

Term	Explanation
AVHRR	Advanced Very High Resolution Radiometer
CAP	Common Agricultural Policy
C	Carbon
CORINE	Coordination of information on the environment
RADAR	Radio Detection And Ranging
SPOT	Satellite Probatoire d'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
STATSGO	State Soil Geographic Data Base
DEM	Digital Elevation Model
EU	European Union
ESDAC	European Soil Database
EUROSTATS	European Statistical Office
FAO	Food and Agriculture Organization of the United Nations
GAEZ	Global Agro-Ecological Zones
GMRCA	Global map of rainfed cropland areas
ISRIC	International Soil Reference and Information Centre
JRC	Joint Research Centre
Magic	Marginal Lands for Growing Industrial Crops
MAIL	Acronym of current project
ML	Marginal Land
MODIS	Moderate Resolution Imaging Spectroradiometer

NASA	National Aeronautics and Space Administration
NPP	Net Primary Productivity
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NDVI	Normalized Difference Vegetation Index
LFA	Less Favoured Areas
LCC	Land-Capability Classification
LULUCF	Land Use, Land Use Change and Forestry
SEEMLA	Sustainable exploitation of biomass for bioenergy from marginal lands
US	United States
USGS	United States Geological Survey
USDA	United States Department of Agriculture
NRCS	Natural Resources Conservation Service
UN	United Nations
UNCCD	UN Convention on Desertification
UNFCCC	United Nations Framework Convention on Climate Change
USGCS	United States Geological Survey

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EXECUTIVE SUMMARY

The scope of this document is to review the state-of-the-art of marginal lands, mainly in a European level, in order to define and classify them.

The concept of marginal land is a dynamic one and dependent of the scale, environment, area, economic sector, etc. and can be derived from multiple variables. In fact, more than one hundred and thirty variables related to environment (soil, climate, productivity, terrain, etc.), land cover or socio-economic aspects have been identified, and almost half of them can be applied using remote sensing. The definition of marginality, or more precisely marginal land, differs according to the final goal of the study.

The notion of land cover and land use and their role in the definition of marginal land are addressed in the present document, especially in the frame of the EU climate action.

Taking into account the above, a definition of marginal land coherent with the objectives of the ***MAIL*** project can be established. This definition is, therefore, the starting point of the project, in which the identification and classification of marginal lands are planned to be applied, among a series of actions aimed at triggering these areas as carbon sinks.

Finally, this deliverable responds to the need to provide a framework for the rest of actions covered in the ***MAIL*** project.

1. INTRODUCTION AND GOALS

This document represents a synthesis of the literature review performed in task T2.1 “Literature review on Marginal Land definition”. The main objective of this document is to establish a solid scientific foundation on which the next stages of ***MAIL*** project will be developed. Publications concerning the definition and identification of marginal lands and identified variables and groups of variables defining marginal lands were reviewed. Special attention was given to the contribution of remote sensing image analysis to the identification of marginal lands.

2. THEORETICAL BACKGROUND

Creation of groups, categorization and classification has always been a useful method to minimize the complexity of the real world (Ahlqvist, 2008). In the case of spatial information, each discipline has developed its own classification system based on specific criteria resulting on a wide range of products (Kellogg, 1951).

Commonly, land surface is characterized by distinguishing land cover types as the simplest way to perform land categorization. Therefore, a significant group of land classification schemes are related to concepts such as land cover and land use (LaGro, 2005; Yang, Li, Chen, Zhang, & Xu, 2017). Di Gregorio (2016) defines land cover as the observed bio-physical cover of the Earth’s surface. Land use in contrast, refers to the purposes for which humans exploit the land cover, which is a result of the complex interactions between the activities performed by a human group in the territory (Verburg, van de Steeg, Veldkamp, & Willemen, 2009).

Classification of lands often implies an evaluation, either qualitative or quantitative, based on resource's characteristics in order to assess land performance for a specified purpose (FAO, 1993). Land evaluation practice has traditionally been developed from the point of view of agricultural capacity for crop growth, implying that land evaluation is largely influenced by soil characteristics. Evaluation in function of a specific land use has been widely applied as well (Rossiter, 1996).

The adjective “marginal” and the noun “marginality” refer to an entity located near at, or constituting a margin, a border, or an edge. Schemes for land classification typically are composed of multiple levels, always existing categories where marginal lands are categorized according the criteria adopted by each discipline in order to define barely adequate lands for a certain purpose.

The importance of sustainability concerns related to resources, biodiversity and climate change is increasing due to the importance of environmental problems. At the same time, ecological knowledge regarding the role of marginal lands in our ecosystems is improving. As a result, requirements for landscape management in general, and marginal lands in particular, are becoming more diverse in order to meet multiple goals (Krcmar, van Kooten, & Vertinsky, 2005)

In this context, defining marginality is a complex matter (Peter, Messina, & Snapp, 2018). For instance, land classified as marginal in a given place or time might be considered as productive (non-marginal) in a different spatio-temporal context (Brouwer, Baldock, Godeschalk, & Beaufoy, 1997; Ciria, Carrasco, Sanz, & Ciria, 2018; Lewis & Kelly, 2014; Sallustio et al., 2018).

Although the concept of marginal land has been broadly applied and discussed especially in relation with the bio-fuel against food production dilemma, this concept is clearly dependent on the discipline and the objectives of the study (Ciria, Sanz, Carrasco, & Ciria, 2019; Dale, Kline, Wiens, & Fargione, 2010). However, a common view of marginality integrating a multi-disciplinary approach is still desirable (Ciria et al., 2019; Kang, Post, Wang, et al., 2013; Peter et al., 2018).

As energy demands increase globally, the concept of marginal land associated with agro-fuel promotion is being widely used both in policies and in scientific literature (Liu et al., 2011). This trend increases the number of studies, and therefore, the number of methodologies developed for marginal land identification and assessment. Unfortunately, many of these studies develop their own definition of the concept (Lewis & Kelly, 2014) and many of the methodologies applied are focused mainly on land productivity, leaving out other factors related to marginality (Liu et al., 2011; Nalepa & Bauer, 2012). The majority of those approaches are static and do not take into account the competition that the bio-fuel use introduces against other uses such agricultural or habitat conservation (Nalepa, Short Gianotti, & Bauer, 2017). (Pérez-Soba et al., 2008)

3. LITERATURE REVIEW

In order to include a systematic approach to the literature review task, the Google Scholar database and its searching tools were used to identify representative papers related to marginal lands. Our searching terms included marginal land as well as other synonymous terms (see Chapter 3.1.2).

The aforementioned searching criteria were applied mainly to obtain documentation about definition and identification methodology. The literature was completed with relevant papers obtained from projects dealing with marginal lands as SEEMLA (Sustainable exploitation of biomass for bioenergy from marginal lands), Magic (Marginal Lands for Growing Industrial Crops) and with generic papers related to marginality and land classification issues.

3.1 Definition of marginal land

3.1.1 Concept development and driving forces

Lately, the term marginal land has been discussed mainly with regard to approaches related to the promotion of bioenergy crops and the impacts of this use on food security and other ecosystem functions (Ciria et al., 2019; Kang, Post, Wang, et al., 2013). The importance of this debate has a clear effect in the relevant scientific literature concerning marginal lands, the production of papers related to the use (and identification) of marginal land for energetic purposes being predominant (Jiang, Jacobson, & Langholtz, 2019; Lewis & Kelly, 2014).

A general definition is that a land is to be considered marginal if yield of agricultural production is smaller or equal to production costs (Ivanina, Roik, & Hanzhenko, 2016). However, the term marginal land may be considered as ambiguous and driven by different forces that cause the marginality of a certain territory. Under the framework of geographical sciences, marginality may arise mainly from unfavourable environmental, cultural, social, political and economic factors (Mehretu, Pigozzi, & Sommers, 2000). Authors such as Jiang et al. (2019), Peter et al. (2018), Sallustio et al. (2018) and Bai, Dent, Olsson, & Schaepman (2008) have stressed the importance of biophysical (environmental) and socioeconomic factors in the marginal land debate. It is commonly accepted that the historical evolution of the concept is related to the driving factors taken into account (Ciria et al., 2018, 2019; James, 2010; Kang, Post, Wang, et al., 2013; Sallustio et al., 2018; Shortall, 2013). Furthermore, marginality is always relative to a certain use, e.g. crop production or livestock grazing (Ivanina et al., 2016; Lewis & Kelly, 2014).

Historically, the concept's starting point is purely economic. The use of economic factors as origin of marginality, and therefore of marginal lands, emerged during the late 19th century through the economic approaches made by Ricardo and Hollander (Ciria et al., 2019; Ivanina & Hanzhenko, 2016; Kang, Post, Wang, et al., 2013). Those first approaches define marginal land as the poorest lands which are used above the margin of rent land payment. Peterson and Galbraith, (1932) continued studying this subject during the beginning of the 20th century, paying more attention to the influence of location in land's profit.

During the 20th and 21st century the economic dimension of marginal lands has been enriched by adding new variables related with markets, policies and technologies. Authors such Wiegmann et al. (2008), James (2010), Cai, Zhang and Wang (2011), Gopalakrishnan, Cristina Negri and Snyder (2011) and Nalepa (2011) represent this approach.

Historically, marginal lands were understood as lands with naturally poor soil or other limiting conditions for agriculture, e.g. steep slopes. However, newer approaches often include degraded areas in their definition of marginality. This includes lands where soil productivity was lost due to human activities such as agriculture or mining (Gerwin et al., 2018; Ivanina & Hanzhenko, 2016; Plieninger & Gaertner, 2011). Characteristics of these marginal lands are salinity or sodicity, contamination, compression, acidity, erosion, loss of organic carbon, and overall productivity loss (Gerwin et al., 2018; Ivanina & Hanzhenko, 2016; Schröder et al., 2018). However, land degradation is not the only cause of land abandonment. Exterior factors like intensification of agriculture, high land prices, or migration due to different causes can lead to the abandonment of agricultural and other activities, leaving potentially productive lands fallow for an extended time (Strijker, 2005). Same problem can be observed in different European mountainous agricultural areas; farmers limit their activities to the most accessible areas they possess due to old age and a lack of successors (MacDonald et al., 2000).

Because of the rise of new management requirements (Krcmar et al., 2005), a broader range of territory planning goals emerged. Within this new framework marginal land definition commences to incorporate concepts related to soil suitability and giving more importance to biophysical limitations related firstly to agricultural productivity and secondly with biological productivity. In this way biophysical and productivity factors responsible for marginality commence to be commonly studied as marginality origin. The main contribution of this new approach is the introduction of the concept of biophysical constraint, that may not be directly associated with crop production like highly erodible soils and ecologically sensitive areas (Kang, Post, Nichols, et al., 2013).

Economic, biophysical and productive factors are closely related. Low economic return from agricultural activity is very often associated with the low crop production and the biophysical constraints affecting the lands. Therefore, marginal land is generally characterized by low food and feed crop productivity, due to soil and environmental limitations (Ciria et al., 2019; Shortall, 2013). The marginal land concept has continued evolving parallel to the concept of ecosystems functions (Wells, Stuart, Furley, & Ryan, 2018). In order to provide the multi-functionality required from the territory nowadays, traditional land functions such economic and activity support, should be compatible with environmental concerns based on long term preservation of ecosystem services (Kang, Post, Nichols, et al., 2013). Thus, the sustainability concept or ecological dimension was integrated into the marginal lands concept as well.

Other authors such as Macdonald and Macdonald, (2009) and Wells et al. (2018) stress the importance of cultural and social factors as driving forces to marginality.

It is generally accepted (Brouwer et al., 1997; Sallustio et al., 2018; Strijker, 2005) that the marginalization of land is deeply influenced by three main aspects or factors:

- environmental (including biophysical factors related to the biological production)
- economic
- demographic and cultural factors

Often, these factors coincide and interact with each other, as in the case of abandonment of economically marginal lands in mountain areas due to demographic change (MacDonald et al., 2000).

3.1.2 Synonyms and related terms

Marginal land is an ambiguous concept often related to terms that could be considered interchangeable. It has been used quite loosely and many times without a clear definition and slight differences in their meaning (Milbrandt & Overend, 2009). In addition, different synonyms of marginal land are used. In the table below we summarized the concepts found during literature review. A graph showing the relative occurrence of each term is attached.

Term	Author
Under-utilized, unused land	Wiegmann et al. (2008), Dauber et al. (2012), Nalepa & Bauer (2012), Shortall (2013), Gerwin et al. (2018), Sallustio et al. (2018)
Idle land	Lovejoy (1925), Wiegmann, et al. (2008), Cai et al. (2011), Bandaru et al. (2013), Shortall (2013), Sallustio et al. (2018), James (2010)
Degraded land	Wiegmann et al. (2008), Cai et al. (2011), Dauber et al. (2012), Shortall (2013), Lewis & Kelly (2014), Sallustio et al. (2018)
Set aside land	Wiegmann et al. (2008), Dauber et al. (2012), Shortall (2013), Lewis & Kelly (2014), Gerwin et al. (2018)
Waste land	Kellogg (1951), Cai et al. (2011), Dauber et al. (2012), Gerwin et al. (2018)
Abandoned land	Wiegmann et al. (2008), Schweers et al. (2011), Lewis & Kelly (2014)
Fallow land	Shortall (2013), Gerwin et al. (2018), Sallustio et al. (2018)
Unproductive land	Lovejoy (1925), Shortall (2013)
Surplus land	Dauber et al. (2012)
Free, spare, additional land	Shortall (2013)

Table 1: Summary of synonyms detected during literature review. Source: personal compilation.

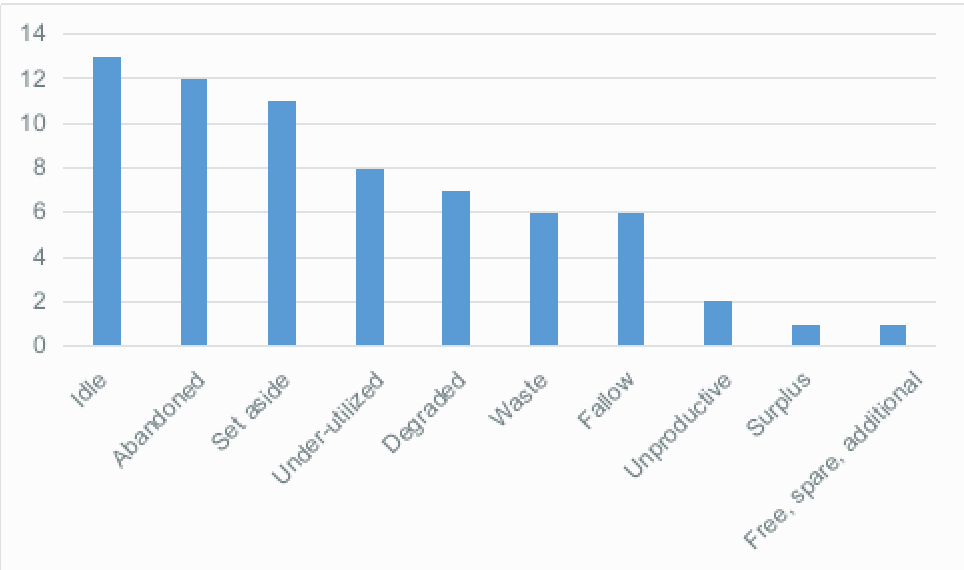

Figure 1: Occurrence of equivalent terms found during literature review. Source: personal compilation.

Within the framework of agricultural production, terminology such as marginal agricultural land, marginal cropland and marginal farming was found during literature review as well (Jiang et al., 2019; Kang, Post, Nichols, et al., 2013). Those concepts are outside of ***MAIL*** scope.

Under European Union legislative framework certain rural areas are classified as Less Favoured Areas (LFA) because of the existence of natural constraints for farming (van Orshoven, Terres, & Tóth, 2014). Less Favoured Areas concept could be considered as a synonym of marginal land.

3.1.3 Types of marginal land definition

As stated by various authors (Brouwer et al., 1997; Dale et al., 2010; Nalepa & Bauer, 2012), there is no a clear and unique definition neither of marginality nor of marginal land. Several formulations of the concept were found in literature and all of them have slight variations according the discipline or the study responding to diverse study objectives (Bertaglia, Joost, & Roosen, 2007; Dale et al., 2010). Definitions found during literature review, together with the aspect or marginality approach that are considered more relevant on each definition are summarized as follows:

Author	Definition	Approach
Ricardo (1817)	Land rent law: A land will be used first since its cultivation relative to poorer quality land results in lower production costs at higher yields.	Economic
Hollander (1895)	"[...] the poorest lands utilized above the margin of rent-paying land".	Economic
Peterson & Galbraith (1932)	"[...] margins of cultivation, where revenues are equal (or lower than) the cost of production".	Economic
Heimlich (1989)	"Marginal lands generally refer to the areas not only with low production, but also with limitations that make them unsuitable for agricultural practices and ecosystem function".	Environmental
Hamdar (1999)	"The land capability classes from IV to VIII characterized by high soil erosion or with some restrictions were generally categorized as marginal lands"	Environmental
Strijker (2005)	"[...] marginal lands have been defined as the land uses at the margin of economic viability".	Economic

Author	Definition	Approach
Schroers (2006)	"[...] an area where a cost-effective production is not possible, under given site conditions, cultivation techniques, agricultural policies as well as macro-economic and legal conditions".	Economic
Bertaglia et al. (2007)	"marginal areas are defined as those areas where possible land uses are relatively limited because of higher altitude, shorter growing season, steeper slopes, less fertile soils or broadly speaking because of generally lower soil productivity."	Environmental & Economic
Macdonald & Macdonald (2009)	"The sense in which this paper uses the term 'marginality' relates to the physical terms of land and climate and the effect on land-related human activity of the environmental limits imposed by these"	Cultural
Milbrandt & Overend (2009)	"Marginal lands are characterized by poor climate, poor physical characteristics, or difficult cultivation. They include areas with limited rainfall, extreme temperatures, low quality soil, steep terrain, or other problems for agriculture".	Environmental
USDA-NRCS (2017)	"[…] the opposite of prime farmland with restrictions of inherent soil characteristics are marginal lands".	Environmental
Dale et al (2010)	"[…] a land where the combination of yield and price barely cover the cost of production".	Economic
Tang, Xie & Geng (2010)	"[…] is evaluated in terms of a cost/benefit analysis and is economically marginal".	Economic
James (2010)	"Marginal land is generally assumed to be land not being used for current production needs, or of such low quality it is ill-suited to modern intensive cropping systems".	Environmental
Cai et al. (2011)	"[…] has low inherent productivity for agriculture, is susceptible to degradation, and is high-risk for agricultural production. In addition, MAL is recognized as an economic term, in which the marginality of the land is related to soil productivity, cultivation techniques, and agriculture policies, as well as macroeconomic and legal conditions".	Economic & environmental
Plieninger & Gaertner (2011)	"[...] economic category which refers to land of poor quality for agricultural or other uses. The term does not factor in subsistence agriculture; marginal lands may deliver ecosystem goods and services to local people. Consequently, "marginal" land may not be considered "degraded" by local people at all."	Economic

Author	Definition	Approach
Schweers et al. (2011)	"[…] land degradation is a long- term loss of ecosystem function and services, not least production, caused by disturbances from which the system cannot recover unaided".	Environmental
Dauber et al. (2012)	"[…] cost-effective production is not possible under given conditions, cultivation techniques, agriculture policies as well as macro-economic and legal settings".	Economic
Liu et al. (2012)	"[…] unsuitable for crop production, but ideal for the growth of energy plants with high stress resistance. These lands include barren mountains, barren lands and alkaline lands".	Environmental
Kang, Post, Nichols, et al. (2013)	"Marginal lands are typically characterized by low productivity and reduced economic return or by severe constraints for agricultural cultivation".	Economic & environmental
Kang, Post, Wang, et al. (2013)	marginal lands as the poorest lands utilized above the margin of rent-paying land	Economic
van Orshoven et al. (2014)	"[…] based on physical constrains for agriculture".	Environmental
Shortall (2013)	"(i) land not fit for food production, (ii) ambiguous lower quality land and (iii) "economically marginal land".	Economic & environmental
Lewis & Kelly (2014)	"[…] characterized by poor and badly drained soils, restricted nutrient and water availability and steep slopes […]".	Environmental
Blanco-Canqui (2016)	"[...] soils that have physical and chemical problems or are uncultivated or adversely affected by climatic conditions."	Environmental
Schröder et al. (2018)	Land that has lost its ecological and/or economical value for the community and is degrading further.	Economic & environmental
Wells et al. (2018)	" [...] defined as social-ecological systems where productivity is severely and persistently limited by biophysical (e.g. soil fertility) and/or socioeconomic factors (e.g. market access)".	Environmental
(Vlachaki, Gounaris, Dimitriadis, & Galatsidas 2018)	"[...] sites that exhibit poor site conditions due to low soil fertility and clear economic inefficiencies with regard to agricultural usability".	Economic & environmental
Ciria et al. (2019)	"From a physical and productive perspective, marginality is based on the levels of soil suitability and restrictions".	Environmental

Author	Definition	Approach
Jiang et al. (2019)	"[...] areas where possible land uses are relatively limited because of higher altitude, shorter growing season, steeper slopes, less fertile soils or broadly speaking because of generally lower soil production".	Environmental

Table 2: Review of marginal land definition. Source: personal compilation

The majority of the definitions reviewed (31), focused on environmental constraints (20) or economic factors (16) and only 6 uses both variables for the definition of marginal lands. The socio-cultural dimensions of marginality are mentioned in only three of the definitions reviewed.

3.1.4 Marginal land as a dynamic and scale dependent concept

The concept of marginality intuitively refers to transitions from unproductive to productive land, or from sub-marginal to supra-marginal land along varying background conditions (Sallustio et al., 2018). This trend is captured in the diagram below:

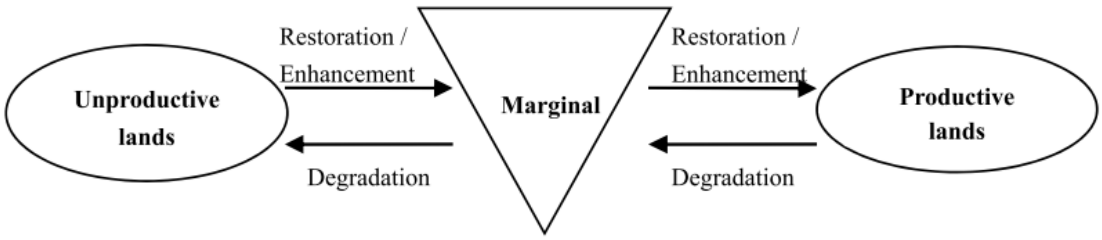

Figure 2: A transitional state of land uses - marginal lands. Source: Kang, Post, Nichols et al. (2013)

Lack or inadequate management in many cases produce land degradation, and marginalized lands can be enhanced or restored to productive lands by improving land functions. However, it has to be considered that lands that temporarily lay fallow as part of crop rotation in traditional agriculture cannot be considered marginal, even though they have all the characteristics of marginal land at a given moment (Ivanina & Hanzhenko, 2016). Other major driving forces affecting the value of marginal lands are market mechanism, policies, incentives and regulations (Kang, Post, Nichols, et al., 2013; Strijker, 2005). Furthermore, lands with variable and unpredictable productivity over the course of several years can be considered marginal (Peter et al., 2018).

Intensification of agriculture especially in the second half of the 20th century through increasing availability of fertilizers had two seemingly contradictory effects on the distribution and frequency of marginal land. Firstly, fewer areas are needed to produce the same yield, so that less productive areas are abandoned; secondly, natural soil quality becomes less important for productivity and naturally marginal lands can become productive for agriculture (Strijker, 2005).

The notion of marginality, hence, is a dynamic term that involves environmental, economic, socio-political or cultural issues that occur in a dynamic network of relationships between people and the environment. Land classified as marginal in a given place or time might be considered as productive (non-marginal) in a different spatio-temporal context (Brouwer et al., 1997; Ciria et al., 2018; Lewis & Kelly, 2014; Sallustio et al., 2018).

Marginal lands can be assessed as a state or condition that can change over time with the emergence of new technologies and demographic shifts (Brouwer et al., 1997; Strijker, 2005; Wells et al., 2018). Based on the general, economic based, definition of marginal lands as lands where production costs are equal to or lower than yield (Brouwer et al., 1997; Ivanina & Hanzhenko, 2016), there are two sides to economic marginality; yield, i.e. possible gain from the land which depends on the amount and the price of the product, and production costs, which are influenced by biophysical, social and technical factors. The balance between these two sides can be changed by external factors such as subsidies or taxes which add to either of the two sides (Brouwer et al., 1997). Those two sides are variable through time, therefore spatio - temporally static characterization of marginality is unable to capture the shifting character of some of the factors that constitute marginality (Nalepa & Bauer, 2012). Marginalization processes take a variety of forms and occur at different scales. For instance, at a local scale, individual agriculturalists may abandon less productive or less accessible parts of their farm due to old age (MacDonald et al., 2000). At a European scale, the abandonment of entire regions in territories of the former USSR due to a combination of migration and intensification of agriculture after 1990 can be observed (Estel et al., 2016; Jaszczak, Kristianova, Vaznonienė, & Zukovskis, 2018; Renwick et al., 2013). Hence, the geographic scale adopted is relevant when defining marginal lands (Bertaglia et al., 2007; Brouwer et al., 1997).

3.2 Marginal lands and environmental concerns

It is commonly accepted that each land use has multiple functions (Batista e Silva, 2011; Gopalakrishnan et al., 2011; Pérez-Soba et al., 2008; Verburg et al., 2009). Usually different land uses are systematically linked through either temporal or spatial interactions. Multi-functionality of land means that every land has the capacity to provide different goods and services. The same applies to lands characterized by the presence of marginal uses or marginal lands. The concept of land's multi-functionality has enormous importance for the study of complex interactions between different land uses and the understanding of temporal and spatial changes. In addition to sustainability, multi-functionality is becoming a guiding principle for many of the current EU policies (Pérez-Soba et al., 2008).

As stated by Allen, Kretschmer, Kieve, Smith, & Baldock (2013), economic returns are commonly related to the term marginal land. However, from an environmental perspective, lands with low economic productivity may not be marginal but instead provide a range of services to society. These ecosystem services, such as carbon storage, water filtration or space for nature are often provided from economically marginal land precisely because these areas are not exploited for another purpose. Particularly, sites which can be classified as marginal offer potentials for biodiversity protection and their use might generate new conflicts, e. g. with nature conservation (Gerwin et al., 2018).

As an example of uses that are taking place in marginal lands, special attention should be given to extensive live stock. Bertaglia et al. (2007) introduce the term marginal areas, where the majority of the marginal lands are concentrated. As stated by those authors, in Europe marginal lands are characteristically used for low-intensity farming systems (low-intensity livestock system), i.e. areas with a proven significant importance for nature conservation. Extensive grazing is especially suitable for marginal lands, being in some extreme cases the only possible use. Extensive land uses represent one of the best adapted alternative in marginal lands and high biological diversity is often associated with these ecosystems (Castro & Castro, 2019). Many ecosystems with high nature values in Europe depend on the continuation of specific forms of extensive land use (Strijker, 2005).

At the same time, there are multiple concerns about environmental impacts, ecosystem services, and sustainability of marginal lands such as erosion, land degradation, biodiversity, and climate change mitigation. Long-term preservation of land functions has become a key component of marginal land concept (Lal, 2009; Wiegmann et al., 2008). Therefore, the marginal land concept has evolved to meet multiple management goals and to incorporate environmental protection, preservation of ecosystem services and long-term sustainability (Kang, Post, Nichols, et al., 2013).

3.3 Categories of marginal lands

As already stated, the term marginal land does not have a unique definition. Categorization of lands is based on the definition of marginal land used by each approach. Therefore, there are different classifications in function of each project's goal.

A simple categorization made in function of a study's goal (suitability for energetic crop production), was applied by Peter et al. (2018), dividing marginal lands in two categories: lands marginally suitable and marginally unsuitable. Agricultural soil suitability was used for the classification. A similar approach and categories were found in Harvolk, Kornatz, Otte and Simmering (2014). Hanzhenko, Roik and Ivanina (2016) propose a more detailed categorization with regard to the same management goal based on biophysical criteria. The categories proposed are shallow rooting, low fertility, stony texture, sandy texture, clayey texture, saline, sodic, acidic, overwet, eroded, and contaminated.

Approaches to identify the quality or fertility of land, has been widely applied for marginal land classification. Those approaches give a ranking score for agricultural land which allows conclusions on the fertility of soils. The US Department of Agriculture (USDA) has published the Land-Capability Classification system (USDA-NRCS, 2017) which is still in use in the USA. Some authors, such as Hamdar (1999), Lovett et al. (2009), Liu et al. (2012) and Gelfand et al. (2013) have used low ranking scores as indicative of marginal site conditions. According to this method land limited in use and generally not suited to cultivation is ranked in groups V -VIII and can be regarded as marginal sites, therefore. In the table below are summarized all classes derived from USDA-NRCS:

Class	Description
I	Slight limitations that restrict their use
II	Moderate limitations that restrict the choice of plants or that require moderate

	conservation practices
III	Severe limitations that restrict the choice of plants or that require special conservation practices, or both
IV	Very severe limitations that restrict the choice of plants or that require very careful management, or both
V	Little or no erosion but have other limitations, impractical to remove, that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat
VI	Severe limitations that make them generally unsuitable for cultivation and that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat
VII	Very severe limitations that make them unsuitable for cultivation and that restrict their use mainly to grazing, forestland, or wildlife habitat
VIII	Miscellaneous areas have limitations that preclude commercial plant production and that restrict their use to recreational purposes, wildlife habitat, watershed, or aesthetic purposes

Table 3 Land Capability Classification system. Highlighted the marginal classes. Source: USDA-NRCS (2017)

Performing a reclassification of land cover categories, Niu and Duiker (2006) use on their study the categories: non-eroded (but limited by other factors), eroded, and severely eroded. On this paper the main objective is the identification of marginal lands with afforestation potential for carbon sequestration.

In the framework of assessing economic marginality on agricultural lands, Sallustio et al. (2018) described three categories:

- Unsuitable agricultural lands: lands with slope >30%, considered unsuitable for agricultural production due to mechanization constraints.
- Supramarginal agricultural lands: lands with high profitability for agricultural production and/or natural conservation constraints.
- Marginal agricultural lands: lands with low profitability for agricultural production.

According to Hanzenko et al. (2016), marginal land categories are as follow: low fertile, stony, acid, saline, eroded and over wet. The aforementioned study's goal is to define marginal lands at European scale for bioenergy crops exploitation.

Wiegmann et al. (2008), identify three categories of marginal land for bioenergy production: land abandoned because of increases in agricultural productivity, land abandoned because of its inferior agricultural performance, and land abandoned for economic reasons such as high income levels in industrial jobs, increasing rents or reduced subsides. Sharing this economic perspective James (2010) categorizes marginal land as lands of low value that are still in production and land enrolled in a specific program (Conservation Reserve Program).

Blanco-Canqui (2016) proposes the following categories of marginal lands with regard to biofuel production and based on the constraints that cause marginality and some uses considered less productive from the agricultural point of view.

- Highly erodible lands
- Reclaimed mine soils
- Flood-prone soils
- Compacted or compaction-prone soils
- Sloping soils
- Acidic and saline soils
- Contaminated soils
- Sandy soils
- Drought-prone soils
- Urban marginal soils
- Abandoned or degraded croplands

Shortall (2013) indirectly proposes a classification of marginal lands clearly related with paper's framework (energy crops). The author discriminates between lands unsuitable for food production, ambiguous (lower quality) lands, and economically-marginal lands.

As it can be seen, categorization is closely related with constrains causing marginality and the study's goals. As detected in definitions, the categorization of marginal land is usually performed focusing on a single aspect of marginality; environmental including constrains for biological production such as hazards or biophysical limits or economical performing a simple cost analysis using specific crop.

3.4 Policies concerning marginal lands

3.4.1 Marginal lands in Europe

As previously noted (see Chapter 3.1.3), there is no single definition of marginal lands. In the same way, such definition does not exist in the European policy landscape (Gerwin et al., 2018). However, for the purposes of this document it could be assumed that, marginal areas are roughly equivalent to those areas which have been classified as less favoured areas (LFA) by the European Commission under the articles of the Less Favoured Areas Directive (European Parliament, 2013). Briefly, the less favoured areas are those where there are limited possible land uses because of altitude, short growing season, steep slopes, infertile soils and low productivity. The aid for the LFA in the European Union dates back to 1975 and has since then undergone several reforms from addressing rural depopulation towards increased focus on maintaining certain agricultural land use and environmental protection. Under the articles of the aforementioned regulation, an area may be classified as less favoured according to one of three categories. Each category characterizes a specific cluster of handicaps, common to certain areas of agricultural land across Europe, and which threaten the continuation of agricultural land use:

- Mountain Areas are characterized as those areas handicapped by a short growing season because of a high altitude, or by steep slopes at a lower altitude, or by a combination of the two. Areas north of the 62nd parallel are also delimited as Mountains.
- Intermediate' Less Favoured Areas are those areas in danger of abandonment of agricultural land-use and where the conservation of the countryside is necessary. They exhibit all of the following handicaps; land of poor productivity, production which results from low productivity of the natural environment, and a low or dwindling population predominantly dependent on agricultural activity.
- Areas Affected by Specific Handicaps are areas where farming should be continued in order to conserve or improve the environment, maintain the countryside, preserve the tourist potential of the areas or protect the coastline.

European Rural Development Policy and Common Agricultural Policy are policies with a deep impact in marginality. These policies have significant impacts in rural areas, been able to modify abandonment of uses and depopulation trends that may lead into marginality (Renwick et al., 2013). Until the 1990s, the majority of EU-budget for agriculture was spent on agricultural market- and price-support, which led to increasing intensification. Today, structural policy and rural development have become increasingly prioritized (Strijker, 2005). Land abandonment in agriculture may also have increased as a side-effect of EU policies promoting set-aside land and afforestation, which may lead to dropping prices for less productive agricultural lands (Strijker, 2005; MacDonald et al., 2000).

The EU has revised its legislative framework in order to meet the requirements for climate change mitigation under the 2015 Paris Agreement. As part of this framework the Land Use, Land Use Change and Forestry (LULUCF) regulation (2018/841) was adopted in May 2018 (European Parliament, 2018). The regulation complements the EU Emissions Trading System that covers energy intensive industries and the power sector and is built around the “no-debit rule”, which requires EU Member States to ensure that emissions from the LULUCF sector do not exceed removals from 2021 to 2030. In other words, the LULUCF sector may not become a net source of GHG emissions, instead, it may become a sink of carbon.

The LULUCF regulation establishes a land-based approach for accounting the emissions and removals from the sector in five land accounting categories: (1) afforested and forested land; (2) managed cropland, grassland and wetland; (3) managed forest land; (4) harvested wood products; and (5) natural disturbances (Romppainen, 2019). Accordingly, not all of the forest management sink will count toward the mitigation target (Grassi et al., 2019), therefore carbon stock contribution, for legal purposes, will depend if we are speaking about already managed forest lands or afforested and forested lands.

3.4.2 Marginal lands in Consortium Member states

Below, in each table, we briefly describe the normative landscape at the national level in each Consortium member state.

Normative	English translation	Sector	Brief description	Relation to marginal lands
Ley 43/2003, de Montes.	Forestry act	Forestry	Legislation concerning the forestry sector, with importance in other aspects as conservation.	Many of m/sm MLs in Spain are under the effects of this legislation. Reforestation
Ley 42/2007, del Patrimonio Natural y de la Biodiversidad.	Natural heritage & biodiversity act	Environment	A general framework for environmental protection. Legislation for the conservation of natural resources and base for the establishment of protected areas.	Because of the important role of ML in ecosystem services.
Real Decreto Legislativo 7/2015, Ley de Suelo y Rehabilitación Urbana.	Royal Decree for land act and urban restoration	Spatial planning	A general framework for spatial planning and development. Define land's use classification basis.	There is no specific normative at national level concerning this sector. Jurisdiction falls in regional governments. The legal framework is extremely variable because of this.
Real Decreto 1378/2018, para la aplicación en España de la Política Agrícola Común	Royal Decree for the implementation of the Common Agricultural Policy in Spain	Agriculture	Transposes the CAP into the Spanish legislation, implementing the cross-compliance and greening and other measures for an efficient and ecological concept for sustainable agriculture.	Because of the effect of CAP in land use change trends (abandon of lands, forestation…), this normative has a significant influence in MLs.

Normative	English translation	Sector	Brief description	Relation to marginal lands
Ley de Cambio Climático y Transición Energética (en preparación)	Climate Change and Energy Transition act (in preparation)	Traversal	The aim of this normative is the reduction (by 2050) of greenhouse gas emissions of at least 90% compared to 1990 levels.	This normative will be one of the three pillars of the Strategic Framework for Energy and Climate, together with the Integrated National Energy and Climate Plan and the Fair Transition Strategy.

Table 4: Summary table of the normative landscape in Spain

Normative	English translation	Sector	Brief description	Relation to marginal lands
FEK 1528/B/07-09-2010	GG 1528/B/07-09-2010	Agriculture	Determination criteria for agricultural land classification in qualities and ranking in productivity categories.	Productivity categories for agricultural land. Possible connection with marginal lands in general.
N. 4351/2015	Law 4351/2015	Livestock raising	Pasture lands detection Pasture lands Management Plans	Lands that might be used as pastures, might also be marginal regarding vegetation and therefore able to be used as carbon sinks. Possible conflicts/ exclusion areas.
FEK 974/B/27-07-2001	GG 974/B/27-07-2001	Desertification	National Action Plan against Desertification based on results of the United Nations Convention for the Combat of Desertification (UNCCD) (signed by Greece in October 1994)	This National Action Plan proposes suitable measures against Desertification that seem in favor of ***MAIL*** scope

Normative	English translation	Sector	Brief description	Relation to marginal lands
N. 4426/2016	Law 4426/2016	Climate Change	Ratification of Paris Agreement (United Nations Framework Convention on Climate Change – UNFCCC)	Strong connection between Paris Agreement and ***MAIL*** scope of detecting MLs in order to be used as carbon sinks

Table 5: Summary table of the normative landscape in Greece

Until now, there is no specific legislation in Greece regarding marginal lands or policy measures regarding their protection. Therefore, only relevant legislative measures are listed below. Some of them might deteriorate the use of MLs as carbon sinks, but they do not set a sound policy framework against ***MAIL*** scope.

Normative	English translation	Sector	Brief description	Relation to marginal lands
Bundesnaturschutzgesetz (BNatSchG)	Federal law for the protection of nature	Environment	Legislation concerning the protection and maintenance of nature and landscapes as well as environmental planning at the federal level.	Because of the important role of ML in ecosystem services.
Bundes-Bodenschutz- und Altlastenverordnung	Federal directive for soil protection and brownfields	Soil, environment	Legislation on soil maintenance, land use and brownfield management	Because some ML may be brownfields or protected soils, and land use change has an influence on soil
Bundesbodenschutzgeset z	Federal Law for soil protection	Soil	Legislation on soil protection and maintenance	Soil is important for marginality; soil quality and soil protection goals may influence afforestation potential

Normative	English translation	Sector	Brief description	Relation to marginal lands
Gesetz zur Erhaltung des Waldes und zur Förderung der Forstwirtschaft (BWaldG)	Law for the preservation of the forest and the advancement of forestry	Forestry	Legislation concerning the forestry sector, with importance in other aspects such as conservation.	Reforestation activities are regulated by this law.
Landwirtschaftsgesetz (LwG)	Agriculture law	Agriculture	Legislation concerning agriculture, including productivity and federal aid for agriculturalists.	Influence on the productivity of types of agriculture.
Bundes-Immissionsschutzgesetz	Federal law for the protection from emissions	Environment, climate	Protection of humans, animals, plants, soil, water, the atmosphere and cultural heritage against emissions. Regulates measures of avoidance and reduction of emissions.	Reforestation for carbon stock is a measure to reduce emissions.
Bundesklimaschutzgesetz	Federal law for climate protection (in preparation)	Environment, climate	Protection of the climate, reduction of emissions	This law will regulate the reduction of emissions as well as other measures against climate change.
Baugesetzbuch (BauGB)	Construction law	Construction, land use	Among other things, the regulation of land use changes.	This law regulates conditions for land use change and priority of land uses.

Table 6: Summary table of the normative landscape in Germany

Normative	English translation	Sector	Brief description	Relation to marginal lands
Ustawa o ochronie gruntów rolnych i leśnych z 3.02.1995 (Dz.U. 2017 poz. 1161)	Law on protection of agricultural and forest soils	Agriculture And Forestry	Legislation regulates the protection of soils, defines possible types of use, obliges to undertake actions in order to avoid soils degradation, puts basis for the soil reclamation.	Defines the concept of ML, regulates reclamation of ML, indicates the rules for the improvement of the value of use of soils
Ustawa o lasach z 28.09.1991 r. (Dz.U. z 2017 r. poz. 788)	Law on forests	Forestry	Legislation concerning the forestry sector. It regulates forest management, forest protection and indicates rules how to increase forest resources.	ML are potential areas which could be forested and the law regulates afforestation actions.
Ustawa o planowaniu i zagospodarowaniu przestrzennym z 27.03.2003 (Dz.U. 2018 poz. 1945)	Law on spatial planning and development of territory	Spatial planning Environment	A general framework for spatial planning and development. Defines land's use classification basis.	Defines rules for shaping of the spatial politics of the regional and national administration. Defines rules for landscape, soils and water protection, as well as puts basis for sustainable development of the local and regional economy.
Prawo ochrony środowiska z 27.04.2001 (Dz.U. 2019 poz. 452)	Law on environmental protection	Environment	Legislation defines rules of environment protection and terms of use of the environment.	The law indicates active forms of environment protection, action for natural compensation and pollution preventing. ML's can be used for these actions.
Ustawa o ochronie przyrody z 16.04.2018 (Dz.U. 2018 poz. 2340)	Law on Nature Conservation	Environment	Legislation is focused on the maintenance of ecological processes and stability of ecosystems, as well as, the conservation of biodiversity and landscape.	ML can play crucial rule in ecosystem services, biodiversity and habitats connectivity.

Normative	English translation	Sector	Brief description	Relation to marginal lands
Prawo wodne z 20.07.2017 (Dz. U. 2017 poz. 1566)	Law on water protection	Environment	Legislation regulates the use of Surface and subsurface water, and water resources protection	ML's can be used as purification areas of ground water form non-point pollution from agricultural sources.

Table 7: Summary table of the normative landscape in Poland

3.5 Identification of marginal lands

Current methods for identifying marginal lands follow the same trend as marginal land definition; methodologies are diverse and reflect specific management goals. In addition, most of them are qualitative, empirical and in many cases very subjective (James, 2010; Kang, Post, Nichols, Wang, et al., 2013). Identification of marginality varies from approaches focused on physical characteristics (i.e. environmental factors) to purely socioeconomic factors that are not spatially explicit, and intended mainly to set up a theory for analyzing landowner decisions on marginal land use (Jiang et al., 2019).

Studies focused on biophysical factors, are mainly based on the conception of land as a productive resource from the agronomic point of view. For Niu and Diuker (2006) the identification of marginal land is based firstly in the identification of agricultural uses (National Land Cover Dataset of the US Geological Survey). Secondly, at this layer of agricultural land, a criteria related with land quality was applied through a soil database. This database classifies land as either prime- or marginal-farmland based on inherent soil properties and climatic characteristics. Marginal-farmlands are the lands that are restricted by various soil physical/chemical properties, or environmental factors, for crop production (i.e. high water table, steep slopes, shallow soils, stoniness, low fertility or frigid temperature regime).

Milbrandt and Overend (2009) obtained most of the marginal lands data in geospatial format from the Global Agro-Ecological Zones (GAEZ system developed by the Food and Agriculture Organization of the United Nations). This system evaluates climatic parameters, topography, soil and land cover to estimate crop suitability and land productivity potential. This study uses soil constraints, climatic constraints, topography datasets and land use and dominant soils data.

The use of suitability indices based on soil rating systems (focused on agricultural production) for the purpose of marginal land identification has been widely applied as well. Cai et al. (2011) applied the index of Soil Rating for Plant Growth (SRPG) developed by the US Department of Agriculture, and the current land cover. This system uses four sets of indices: soil productivity properties, slope, soil temperature regimes, and humidity index. Soil productivity is computed according to 16 soil properties. Aggregation of factors is being performed applying score rules for each variable through a fuzzy approach.

A similar approach based on a suitability indicator for agriculture activity, was applied by Li et al. (2017), using eight indicators (slope, soil erosion, soil organic carbon, texture, pH, cation exchange capacity, soil depth and drainage). Aggregation through different statistical methods was accomplished. After masking out some restrictions (human settlements, water or protected areas), the remaining areas were grouped into five classes according to their suitability for agriculture – highly suitable, moderately suitable, marginally suitable, marginally not suitable, and permanently not suitable.

In the framework of the SEEMLA project (acronym for sustainable exploitation of biomass for bioenergy from marginal lands), and using a soil rating system, Gerwin et al. (2018) applied the biophysical criteria suggested by van Orshoven et al. (2014) to describe and define natural constraints for agriculture in Europe. To assess soil quality, or conversely marginality, the Muencherberg Soil Quality Rating system (Mueller, Schindler, Behrendt, Eulenstein, & Dannowski, 2007) was calculated on the basis of a set of generic soil parameters and hazard indicators. Under this approach, marginal lands were defined based on the scoring scheme of the system, being considered as marginal the lands with score below 40 due to their poor production potential.

Sustainability concerns and economic approach were integrated into marginal land identification performed by Gopalakrishnan et al. (2011). The identification of marginal lands is based, firstly, on the basis of soil health criteria: eroded land, frequently flooded, poorly drained, highly sloped, and low productivity for grain crop. Secondly, a set of lands is added on the basis of current land use, including land categories such as idle and fallow croplands. The third approach or attempt is based on environmental degradation: brownfield sites and contaminated sites, contamination of water resources, land where irrigation is significant and could lead to depletion of water resources.

The use of biophysical constraints related with agricultural productivity is commonly applied for marginal land identification. Despite not being spatially explicit, Liu et al. (2011) make a proposal of parameters useful to identify marginal lands based on biophysical constraints and land uses. Kang, Post, Wang et al. (2013) and Ciria et al. (2019) apply a holistic approach for marginal land identification, combining biophysical constraints with economic yield of agricultural crops and others sustainability concerns.

According to Gelfand et al. (2013) marginal land identification can be performed based in the Land-Capability Classification (LCC) developed by the US Department of Agriculture (USDA). Based on this method, marginal lands were identified as rural lands falling into classes V-VI, giving special importance to slope constraints and land cover.

Purely socioeconomic studies are mainly conceptual, not spatially explicit, and in many cases aim to model land use change trends or answering questions about how to use marginal lands (Jiang et al., 2019). Generally, biophysical methodologies reviewed are spatially explicit falling somewhere in between, first identifying land as marginal relative to a select land use (land use understood as indirect indicator of socioeconomic factors), and then may or may not refine that target set of lands with soil quality.

A slightly different approach was applied by Bertaglia et al. (2007), due to the fact that authors' framework (extensive grazing) requires a different approach to marginality. The main difference of this approach is the consideration of land cover/use as an aggregate of biophysical limitations and socioeconomic trends. Thus, the authors introduce the term of marginal areas based on the percentage of less productive versus productive uses.

In the table below we categorize the identification methods analysed in this document according to the variables utilized for marginal land identification. All variables were grouped according to their relation to marginality driving forces, i.e. to environmental or socio-economic factors (for further information see Chapter 3.1.1). For variables related to land cover/use or productivity, separate categories were created due to the fact that those variables are influenced by environmental, social and economic factors. Environmental factors were grouped as well in variables related with soil, climate, terrain (i.e. slope) and sustainability concerns (i.e. erosion risk and contamination).

Study	**Environmental variables**				**Productivity**	**Land cover /use**	**Socio-economic**
	Soil	**Climate**	**Terrain**	**Sustainability concerns**			
Bai et al. (2008)		√			√	√	
Bertaglia et al. (2007)						√	√
Cai et al. (2011)	√	√	√			√	
Ciria et al. (2018)	√	√			√		

Study	Environmental variables				Productivity	Land cover /use	Socio-economic
	Soil	Climate	Terrain	Sustainability concerns			
Gelfand et al. (2013)	√	√	√			√	
Gerwin et al. (2018)	√	√	√	√			
Gopalakrishnan et al. (2011)	√		√	√	√	√	
Kang, Post, Wang et al. (2013)	√	√	√	√	√		√
Li et al. (2017)	√	√	√	√		√	
Liu et al. (2011)	√		√			√	
Milbrandt & Overend (2009)	√	√	√			√	
Niu & Duiker (2006)				√	√	√	

Table 8: Methods for marginal land identification. Source: personal compilation

3.6 Remote sensing and marginal lands

For objective identification of underutilized lands at a regional or global scale, remote sensing and modern interpretation techniques are increasingly used (Nalepa & Bauer, 2012). Many of the parameters and groups of variables described above (Chapter 3.5) are linked to land use / land cover or specific characteristics of the Earth's surface. This especially applies to biophysical criteria. Out of ten research papers on marginal land classification (see Table 9), one is based on a direct derivative of remote sensing data, namely a Normalized Difference Vegetation Index (NDVI), which is used to estimate productivity (Bai et al., 2008). Five other researches use data products indirectly based on remote sensing, specifically land use and land cover data (Cai et al., 2011; Gopalakrishnan et al., 2011; Li, Messina, Peter, & Snapp, 2017; Milbrandt & Overend,

2009) and soil data (Ciria et al., 2018). Land abandonment can be identified by comparing multi-temporal land use or land cover data (Estel et al., 2016). Degradation of land productivity can be assessed using multi-temporal Normalized Difference Vegetation Indices (Gibbs & Salmon, 2015; Löw, Fliemann, Abdullaev, Conrad, & Lamers, 2015). Net primary productivity (NPP) is available as a data product based on the NDVI derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) and can be used for multi-temporal analyses (Peter et al., 2018).

Author	Group of variables	Data source	Remote sensor / mission
Bai et al. (2008)	Climate	Rainfall dataset	-
	Productivity	Normalized difference vegetation index (NDVI) data	Advanced Very High Resolution Radiometer (NOAA - AVHRR)
	Land cover/use	Global Land Cover 2000 database. European Comission (JCR)	VEGETATION instrument on board the SPOT 4 satellite (SPOT - VGT)
Bertaglia et al. (2007)	Land cover/use	CORINE land cover database	Derived from SPOT 4 and Landsat 7
	Socio-economic	EUROSTAT database	-
Cai et al. (2011)	Soil	Harmonized World Soil Database (FAO)	-
	Climate	Various sources	-
	Terrain	USGS/NASA SRTM DEM	Directly derived from the Global Terrain Slope from the Shuttle Radar Topography Mission
	Land cover/use	Land Use and Cover Change dataset. International Geosphere-Biosphere Programme.	1992–1993 AVHRR 1-km. Directly derived from Global map of rainfed cropland areas (GMRCA) created through remote sensing data (NOAA - AVHRR and SPOT - VGT)
Ciria et al. (2018)	Soil	SoilGrids (ISRIC - World Soil Information)	Dataset derived through combination of soil profiles remote sensing-based (MODIS),SRTM DEM data derivatives, field measures and machine learning algorithms.
	Climate	Rainfall dataset	-
	Productivity	Production cost for cereal in Spain	-

Author	Group of variables	Data source	Remote sensor / mission
Gelfand et al. (2013)	Soil	Soil Survey Geographic data from US Department of Agriculture	-
	Climate	Time series	-
	Terrain	USGS/NASA SRTM DEM	Directly derived from the Global Terrain Slope from the Shuttle Radar Topography Mission
	Land cover/use	Cropland Data Layer of the National Agricultural Statistics Service (USGCS)	Landsat 5, Landsat 7 and IRS-1C LISS 3 (Mueller & Seffrin, 2006)
Gerwin et al. (2018)	Soil & Sustainability concerns	European Soil Database (ESDAC, JCR) and Harmonized World Soil Database (FAO)	-
	Climate	WorldClim database	-
	Terrain	USGS/NASA SRTM DEM	Directly derived from the Global Terrain Slope from the Shuttle Radar Topography Mission
	Land cover/use	CORINE land cover database	Derived from SPOT 4 and Landsat 7

Author	Group of variables	Data source	Remote sensor / mission
Gopalakrishnan et al. (2011)	Soil, terrain & productivity	Soil database STATSGO (USDA-NRCS)	The dataset was created by generalizing more detailed soil survey maps. Where more detailed soil survey maps were not available, data on geology, topography, vegetation, and climate were assembled and related to Land Remote Sensing Satellite (LANDSAT) images.
	Sustainability concerns	Brownfields, groundwater quality, irrigation datasets	-
	Land cover/use	2007 Land use database (USDA, 2007)	Landsat 5, Landsat 7 and IRS-1C LISS 3 (Mueller & Seffrin, 2006)
Kang, Post, Wang et al. (2013)	Soil, climate, terrain, sustainability concerns, productivity, soico-economic	Soil Survey Geographical Databases (SSURGO, USDA)	-
Li et al. (2017)	Soil	SoilGrids (ISRIC - World Soil Information)	Dataset derived through combination of soil profiles remote sensing-based (MODIS),SRTM DEM data derivatives, field measures and machine learning algorithms.
	Climate, sustainability concerns	WorldClim database	-
	Terrain	USGS/NASA SRTM DEM	Directly derived from the Global Terrain Slope from the Shuttle Radar Topography Mission
	Land cover/use	Malawi Spatial Data Platform	Landsat

Author	Group of variables	Data source	Remote sensor / mission
Liu et al. (2011)	Soil, terrain, land cover/use	Literature review	-
Milbrandt & Overend (2009)	Soil	Harmonized World Soil Database (FAO)	-
	Climate	Time series	-
	Terrain	USGS/NASA SRTM DEM	Directly derived from the Global Terrain Slope from the Shuttle Radar Topography Mission
	Land cover/use	FAO's GeoNetwork	Based on multiple data sources, including satellite images
Niu & Duiker (2006)	Sustainability concerns & productivity	Soil database STATSGO (USDA-NRCS)	The dataset was created by generalizing more detailed soil survey maps. Where more detailed soil survey maps were not available, data on geology, topography, vegetation, and climate were assembled and related to Land Remote Sensing Satellite (LANDSAT) images.
	Land cover/use	National Land Cover Dataset (NLCD-USGS)	Landsat TM

Table 9: Data sources used for marginal land classification and their link to remote sensing

Furthermore, some of the parameters for the identification of marginal lands listed above are routinely derived from remote sensing data. Surface soil moisture, which is indicative of overwet soils and can be used to estimate drainage combined with climate data (Mattikalli, Engman, Ahuja, & Jackson, 1998), can be quantified using active or passive microwave sensors (Apan et al., 2002; Mulder, de Bruin, Schaepman, & Mayr, 2011; Santanello et al., 2007; Selige, Böhner, & Schmidhalter, 2006; Zhai, Thomasson, Boggess, & Sui, 2006). Soil organic carbon content at the surface is negatively correlated to reflectance in the visible and NIR spectra. However, this applies to other soil characteristics, e.g. clay content and humidity, as well (Bartholomeus, 2009; Mulder et al., 2011; Niwa, Yokobori, Hongo, & Nagata, 2011; Selige et al., 2006; Sumfleth & Duttmann, 2008). Severely saline soils may be detected using multispectral, microwave or Thermal Infrared remote sensing imagery (Metternicht & Zinck, 2003; Mulder et al., 2011). Soil texture, i.e. clay, sand and silt content, can be derived from multi- or hyperspectral remote sensing imagery (Apan et al., 2002; Mulder et al., 2011; Selige et al., 2006; Zhai et al., 2006) or from drainage using complex models (Santanello et al., 2007). Active microwave sensors (RADAR) can be used to estimate plant biomass, thus giving an indication of land productivity. Furthermore, existing datasets such as the NASA State Soil Geographic Database and most land use / land cover maps are based on remote sensing data combined with field measurements.

4. RESULTS

4.1 Common definition of marginal land

As depicted in previous chapters, and in accordance with Peter et al. (2018), defining marginality is a complex matter as its origin is multi-causal and interacts at many scales, both spatial and temporal.

Due to the fact that the marginal land concept is clearly dependent on the discipline and the objectives of the study as stated by Ciria et al. (2019) and Dale et al. (2010) (see Chapter 3.1.2), multiple definitions and terms related to “marginal lands” exist as summarized in Table 1 and Table 2.

A general view on marginal lands is required, arising from a multi-disciplinary approach (see Chapter 2) and taking into consideration that marginality may arise from unfavourable environmental, cultural, social, political and economic factors, i.e. driving forces of marginality (see Chapter 3.1.1).

In Chapter 3.2 the importance of environmental concerns has already been stated. Thus marginal lands play an important role for ecosystem stability and the fact that a piece of land is classified as "marginal" does not imply that its function is less important or trivial. Land uses are systematically linked through either temporal or spatial interactions, and the capacity to provide different goods and services should be taken into account. Particularly, sites which can be classified as marginal offer potentials for biodiversity protection and their use might generate new conflicts, e. g. with nature conservation. In addition to sustainability, multi-functionality is becoming guiding a principle for many current EU policies.

As stated by many authors, economic returns are commonly related with the term marginal land, which is a key concept in the definition of considerable areas, but not the only one (Chapter 3.1.1).

The definition of marginal land should be compatible with the dynamism that implies marginality as a process (see Chapter 3.1.4) that involves environmental, economic, socio-political or cultural issues that occur in a dynamic network of relationships between people and the environment.

Land uses such as extensive grazing are especially suitable for marginal lands, being in some extreme cases the only possible use (see Chapter 3.2). It should be noted that many ecosystems with high nature values in Europe depend on the continuation of specific forms of extensive land use that should be taken into account when defining the socioeconomic factors that influences marginal lands definition.

4.2 Differences between definitions of marginal land

Among scientists, there is a big uncertainty regarding the usage of the term marginal due to its multi-casual origin (see Chapter 2). This fact has a direct effect on marginal land definition. In spite of the relative consistency of the definitions reviewed (see Chapters 3.1.2 and 3.1.3) in the sense that all of them recognize the importance of constraints as a "key" concept to define marginal lands, uncertainty is reflected in their working definitions.

Each definition is focused on different aspects of marginality according to research scopes, resulting in the use of marginal lands as a miscellaneous term that includes many types of lands ranging from fallow and abandoned land to degraded land. The unclear definition of marginal land is considered an important problem of this kind of studies.

As shown in Table 2, the majority of the definitions reviewed are focused on a single aspect or approach to marginality (environmental, economic or social see Chapter 3.1.1). Twenty out of the total (31) found mainly focused on biophysical constraints for agricultural production, i.e. environmental factors, and only six mention the existence of other constraints related to the system's sustainability, such as erodibility or water contamination. Sixteen take economic factors into account and only six include both approaches. The socio-cultural dimensions of marginality are mentioned in only three of the definitions reviewed.

All of the studies listed in Table 2 show the lack of a common working definition, using mainly environmental (biophysical) factors in order to define marginal lands, sometimes combined with economic factors. This ambiguity of marginal land definitions is recognized by authors such as Sallustio et al. (2018) and Shortall (2013) that suggest that two main groups of definitions can be defined according to marginality origin: those related to biophysical aspects and those based on the socio-economic context. According to Lewis and Kelly (2014) dissimilarities between definitions are strongly related to the working scale at which marginality is being assessed.

As stated by Nalepa (2011) biophysical characterizations should not be considered sufficient to determine the marginality of one parcel of land since there are many factors that influence land productivity. Current definitions lack integration of biophysical and socioeconomic considerations in the marginal land analysis (Jiang et al., 2019).

The difference between definitions and working methodologies is more obvious if the study is completed with a spatially explicit attempt of marginal land identification. Despite the fact that almost all definitions are influenced both by environmental and socioeconomic factors, analysing the inputs utilized by each method for identification of marginal land, the great importance assigned to biophysical factors becomes obvious. Many times, land cover/use is used as the only aggregator of social and economic factors. This fact should be taken into account when defining the methodology for marginal land definition. In the same way, methodologies for marginal land identification do not follow the indication from the definition regarding the dynamic condition of marginal lands.

4.3 Constraints concerning marginal land

Taking into consideration the influence of research objectives on marginal land definition, it is necessary to include some constraints imposed by ***MAIL*** objectives such as:

1) In order to avoid unwanted effects on the agri-food sector, agricultural lands, should be excluded from the definition of marginal lands adopted by ***MAIL***.

2) Related to the previous constraint, the ***MAIL*** framework focuses on marginal lands in mountainous and semi-mountainous locations. In addition, within mountain regions, difficult production conditions lead to low harvests and high costs. Slope is considered a constraint for agricultural production (Bertaglia et al., 2007). Existing farming systems are often small-scale and low-intensity to adapt to restrictive conditions. This makes them particularly prone to abandonment (MacDonald et al., 2000). Mountainous agricultural areas are often considered particularly valuable for the environment. Their abandonment often leads to a decrease in biodiversity. Afforestation of abandoned mountainous agricultural lands should be implemented carefully and with consideration of local conditions (MacDonald et al., 2000).

3) Protected areas should be excluded from ***MAIL*** definition as a result of the importance of sustainability concerns that is a part of the marginal land concept and the brand new management requirements.

4) Because the main objective of ***MAIL*** project is the increase of C stock under the “umbrella” of the LULUCF directive, those lands in which activities such as forestation and reforestation have more impact on the emission accounting system as defined by the aforementioned regulation, should be prioritized in comparison with other possible marginal lands.

5. CONCLUSIONS

5.1 Proposal of marginal land definition

Based on what has been stated so far, and taking into consideration that the definition of marginal land is the basis on which the ***MAIL*** project will be developed, the definition must meet the following objectives:

- Collect the relevant scientific aspects related to marginality as described above.
- Be compatible with, and collect the objectives of the ***MAIL*** project

The definition should include the following aspects:

1. Marginality is caused by various constrains.
2. The definition of marginal lands should integrate environmental, economic and social factors as all of them are causes of marginality. A definition of marginal lands that is only based on environmental parameters (i.e. biophysical factors) is not complete from a theoretical point of view.
3. Dynamic and variability of marginal land should be explicitly included in the definition:
   a) Dynamic from a temporal point of view.
   b) Scale and location dependent.
4. The definition must consider specific restrictions of the ***MAIL*** project, according to the project's goals.
   a) From the full set of marginal lands detected, those more relevant for the emission accounting system as stated in LULUCF regulation, should be considered as ***MAIL's*** marginal land.
   b) Agricultural lands will be excluded from ***MAIL*** marginal lands, avoiding the generation of new pressures on this use.
   c) Protected areas will be excluded from ***MAIL*** marginal lands, to avoid conflicts with environment conservation.
   d) Other local uses should be taken into account (i.e. extensive livestock or tourism).

To sum up, marginal lands for the ***MAIL*** project are:

Lands with significant, either environmental (biophysical variables) or socioeconomic, constraints and with potential to impact national accounting for C stock, excluding agricultural lands and other valuable areas (protected areas, uses with local importance etc.). Dynamic and variability are key concepts for marginal land identification.

Examples of these areas include, but are not limited to, degraded and / or abandoned lands, lands with naturally low productivity due to biophysical constraints, and other degraded lands that have not (yet) been converted to other uses, e.g. post-industrial and post-mining sites.

In a complement approach, fully consistent with the ***MAIL*** project objectives, we will consider Marginal Lands those whose land use allows, according to accounting rules referred in the EU commitment and the regulation developed (European Parliament. Regulation (EU) 2018/841) and land use categories proposed by the 2006 IPCC guidelines (IPCC. (2006)), to maximize the increase of carbon stock. That is, ***MAIL*** project will focus on areas in which it is possible to convert them to forest lands (Land Converted to Forest Land: *afforested lands*).

Therefore, it can be considered Marginal Lands, grasslands (including systems with woody vegetation which do not comply with minimum values for the variables specified in the Annex II for each country), abandoned croplands or other lands (bare soil, rock, ice, etc.), excluding from them those with social-economic activity, environmental protection or with legislative restrictions.

The figure below shows the flow chart that represents the transition between marginality and the definition on marginal lands in the framework of ***MAIL*** project.

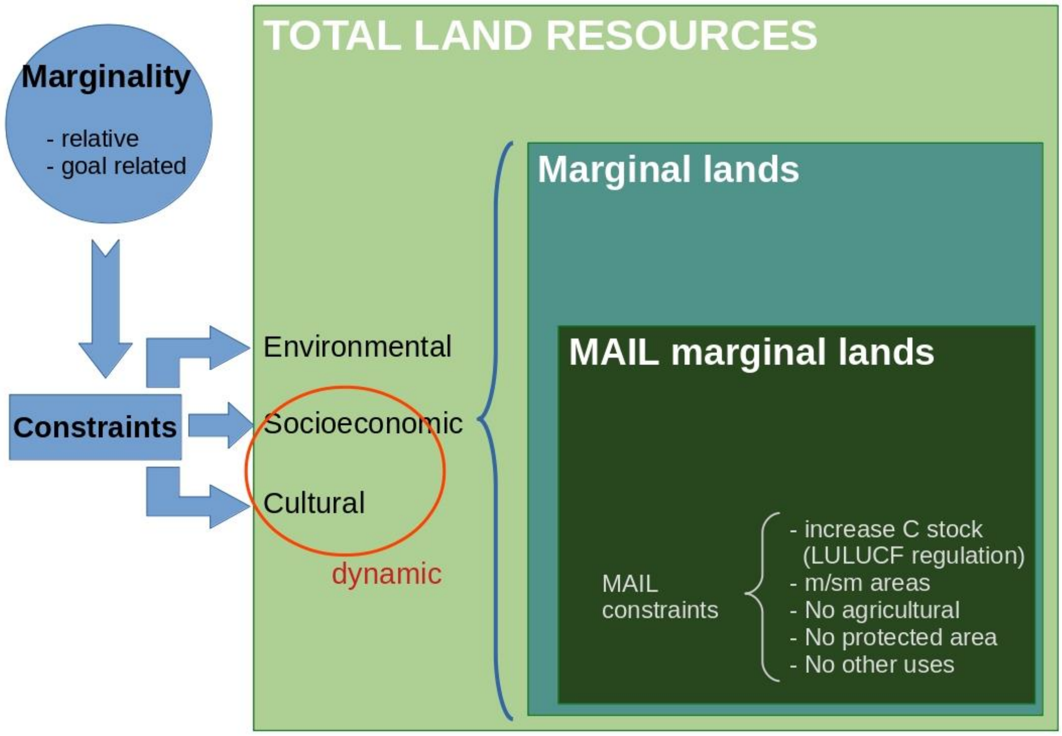

Figure 3: Transition between marginality and the definition on marginal lands in the framework of MAIL project.

5.2 Identification approaches of marginal lands

Under the framework of marginal land definition review, it was found in many cases that definitions are closely linked to methodologies and factors utilized for marginal land identification. Therefore, together with a proposal of marginal land definition, we are in a position to offer some preliminary conclusions concerning identification methods, variables and the potential of remote sensing image analysis for marginal land classification.

As stated in previous chapters, marginal lands within the ***MAIL*** project are a complex and variable category, which can have different meaning depending on local conditions and scale. There are multiple factors potentially influencing marginality and spatial-temporal, economic, and social dynamics have to be taken into account. In order to develop an implementable methodology for marginal land classification at the European scale, it is necessary to break down these aspects of marginality to assessable factors that can be derived from available data with reasonable effort.

Our literature research, as presented above, showed that most authors use a combination of land use / land cover and soil data to classify marginal lands. Additionally, climate, socio-economic and elevation data were regularly taken into account. The temporal dimension was investigated by evaluating multi-temporal datasets in order to assess land use and land productivity trends. Spatial classification was mostly implemented through some kind of geographic overlay of input data, using either a combination of binary constraints or fuzzy logic for marginal land classification. Constraints were divided into “soft” or “hard” constraints, “soft” constraints being factors with variable thresholds (e.g. elevation) and “hard” constraints binary exclusion factors, e.g. protected areas.

Most factors indicative of marginality derived from the research papers we reviewed (see Annex I for a complete list of variables reviewed) can be seen as “soft”. These include biophysical factors such as slope, elevation, soil quality / fertility and erodibility, which are inherent properties of the land or soil, as well as dynamic factors derived from multi-temporal trend analysis. Decreasing productivity is an important indicator of marginality and can be derived from multi-temporal Normalized Difference Vegetation Index (NDVI) or Net Primary Productivity (NPP). However, reasons for land abandonment are not always spatially explicit. The overall economic, technological and demographic developments in a region can lead to land becoming underutilized in spite of relatively high potential productivity. This factor can be taken into account by analyzing land use trends, preferably over several decades.

Current land use and policy can be classified as “hard” constraints with regard to marginal land classification. Land that is currently in active use for agriculture cannot be seen as marginal, even if it has all characteristics of marginal land. This includes lands temporarily fallow as part of crop rotation. Protected areas are also excluded from marginal land classification within the ***MAIL*** project.

Identification and quantification of these criteria is a complex task. There currently is no one single dataset or classification technique which includes all of the different factors. Furthermore, many aspects, especially socioeconomic and social ones, are not spatially explicit. Remote sensing data can be an important input for the identification of marginal lands. In most literature concerning marginal land detection reviewed for this paper, the analysis was based on remote sensing imagery or its derivatives, specifically soil and land use / land cover data (see Chapter 3.5). In particular, remote sensing appears to be the approach of choice for multi-temporal and small-scale, i.e.

global, continent-, or nation-wide analyses. Other datasets such as (historical) soil and geological maps, cadastral or topographic maps often contain different classes depending on the country and region and are not available for all regions of Europe at the same level of quality and detail.

However, classification of marginal lands based on remote sensing data faces several limits. In general, (open) satellite imagery is available since about 1980, which makes it impossible to investigate long-term trends and developments (Gibbs & Salmon, 2015). Furthermore, remote sensing images show one exact moment in time and give no indication of the causes of developments. Without additional information, it is impossible to distinguish between marginal and temporarily fallow land (Ivanina & Hanzhenko, 2016). This issue can only partly be circumvented by the use of multi-temporal data. For many classification approaches, it is necessary to include extensive ground truth data both for the development of the classification approach and for validation (ibid).

Many datasets that can be of relevance for marginal land detection are derived from remote sensing data, e.g. international land use and land cover, digital elevation models, or soil maps. In these cases, it is necessary to critically evaluate the quality and scale of the data. Errors propagate through classification and an inappropriate scale can lead to inaccuracies (Nalepa, 2011).

Data availability and reliability with regard to different parameters is taken into account for parameter selection; even if a parameter is very suitable to determine marginality in theory, it should not be included in the research if there is no realistic way to generate a high-quality estimate of this parameter based on available data at a scale suitable for the research.

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ANNEX I: VARIABLES REVIEWED FOR MARGINAL LAND IDENTIFICATION

Group of variables	No of times variable is used	No of times variable is used and related to RS
Environmental		
Soil	80	27
Climate	9	1
Productivity	4	4
Sustainability concerns	9	3
Terrain	17	14
Sub total	**119**	**49**
Land cover	9	8
Socio-economic	9	1
Total	**137**	**58**

Group of variables	Variable	No of times variable is used	No of times variable is used and related to RS
Texture/ structure	Soil depth	5	3
	Clay content	4	
	Drainage	4	3
	Soil type (Texture)	4	2
	Bulk density	2	
	Sand content	3	1
	A horizon depth	1	
	Available water capacity in the root zone	1	

Group of variables	Variable	No of times variable is used	No of times variable is used and related to RS
	Depth to restrictive layer	1	
	Eroded	1	1
	High % coarse soil texture fragments	1	
	layer depth	1	
	Moisture	1	1
	Permeability	1	
	Profile available water	1	
	Rooting depth	1	
	Soil layer restriction	1	1
	Soil substrate	1	
	Stoniness	1	1
	Subsoil compaction	1	
Sub total		**38**	**14**
Chemical properties	ph	8	3
	Soil organic matter	5	3
	Carbonates	3	
	Cation exchange capacity	3	2
	Gypsum	3	
	Salinity	3	1
	Natural fertility	2	
	Peat soil	2	
	Salinization	2	1
	Bedrock depth	1	1
	Electric conductivity	1	

Group of variables	Variable	No of times variable is used	No of times variable is used and related to RS
	Low total nutrient status	1	
	nitrogen	1	
	number of soil layers	1	
	Rock at surface	1	
	Rock fragment	1	1
	Sodicity	1	1
	Sodification	1	
	Sodium adsorption ratio	1	
	Soil depth above rock	1	
Sub total		**42**	**13**
Total		**80**	**27**

ANNEX II: MINIMUM VALUES FOR AREA SIZE, TREE CROWN COVER AND TREE HEIGHT PARAMETERS.

Member state	Area (ha)	Tree crown cover (%)	Tree Height (m)
Belgium	0,5	20	5
Bulgaria	0,1	10	5
Czech Republic	0,05	30	2
Denmark	0,5	10	5
Germany	0,1	10	5
Estonia	0,5	30	2
Ireland	0,1	20	5
Greece	0,3	25	2
Spain	1,0	20	3
France	0,5	10	5
Croatia	0,1	10	2
Italy	0,5	10	5
Cyprus	0,3	10	5
Latvia	0,1	20	5
Lithuania	0,1	20	5
Luxembourg	0,5	10	5
Hungary	0,5	30	5
Malta	1,0	30	5
Netherlands	0,5	20	5

Member state	Area (ha)	Tree crown cover (%)	Tree Height (m)
Austria	0,05	30	2
Poland	0,1	10	2
Portugal	1,0	10	5
Romania	0,25	10	5
Slovenia	0,25	30	2
Slovakia	0,3	20	5
Finland	0,5	10	5
Sweden	0,5	10	5
United Kingdom	0,1	20	2

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