D5.1 Guide on success stories for RS techniques and open source data / applications

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

Project title	Identifying Marginal Lands in Europe and strengthening their contribution potentialities in a CO2 sequestration strategy
Call identifier	H2020 MSCA RISE 2018
Project acronym	MAIL
Starting date	01.01.2019
End date	31.31.2021
Funding scheme	Marie Skłodowska-Curie
Contract no.	823805
Deliverable no.	D5.1
Document name	MAIL_D5.1.pdf
Deliverable name	Guide on success stories for RS techniques and open source data/applications
Work Package	WP5
Nature[1]	R
Dissemination[2]	PU
Editor	Homeotech, CBK PAN, Chalampos Georgaidis (AUTH)
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Date	30.12.2021

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

[2] **PU** = Public, **PP** = Restricted to other programme participants (including the Commission Services), **RE** = Restricted to a group specified by the consortium (including the Commission Services), **CO** = Confidential, only for members of the consortium (including the Commission Services).

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ABBREVIATIONS

Term	Explanation
DAB	Diameter at breast height
CORINE	Coordination of Information on the Environment
FM	Forest management
GLCC	Global Land Cover Characterization
MCDA	Multi-criteria decision analysis
MLM	Marginal land management
NOAA	National Oceanic and Atmospheric Administration
RS	Remote Sensing
SW	Software
EU	European Union
ML	Marginal Land
CO2	Carbon Dioxide
GIS	Geographic Information Systems
RS	Remote Sensing
FAO	Food and Agriculture Organization
SFM	Sustainable Forest Management
MOOC	Massive Open Online Course
MAIL	Identifying Marginal Lands in Europe and strengthening their contribution potentialities in a CO2 sequestration strategy
SEEMLA	Sustainable exploitation of biomass for energy form Marginal Lands
MAGIC	Marginal Lands for Growing Industrial Crops
LULUCF	Land Use, Land Use Change and Forestry

MIS	Management Information System
MCDA	Multi Criteria Decision Analysis
GNU / GPL	General Public License
OSD	Open Source Definition
OSI	Open Source Initiative
FSF	Free Software Foundation
BSD	Berkeley Source Distribution
QGIS	Quantam GIS
WFS	Web Feature Service
WMS	Web Map Service
SDE	Software Development Engineer
GIF	Graphics Interchange Format
JPEG / JPG	Joint Photographic Experts Group
PNG	Portable Network Graphics
BMP	Bitmap
USGS	United States Geological Survey
DEM	Digital Elevation Model
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
SWIR	Short Wave Infrared
NDWI	Normalized Difference Water Index
NDSI	Normalized Difference Snow Index
AVHRR	Advanced Very High Resolution Radiometer

| SPOT | Satellite for observation of Earth |
| EO | Earth Observation |

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EXECUTIVE SUMMARY

In the case of the *MAIL* project, success stories for RS techniques and open-source data / applications can be compared to the monitoring and management of a forested area. The major goal of the *MAIL* project is to utilize marginal lands as carbon sinks, with an emphasis on generating forest growth on lands that previously had or lacked it naturally, i.e., land reforestation or afforestation.

This deliverable intends to improve and monitor pre-plant soil treatments, silvicultural treatments (including brush clearing), tree growth monitoring, and phytosanitary treatments at various phases of tree growth. The project's objectives are exceeded by the comprehensive development of forest management, which includes all administrative, economic, legal, social, technological, and scientific aspects of natural and planted forests. It explains the forest carbon cycle, different definitions and categories of ML in Europe in depth based on relevant literature reviews. The second goal of this deliverable is to give guidance for future marginal land exploitation and management by any relevant actor in Europe, with a focus on the use of marginal lands as carbon sinks through afforestation and reforestation projects.

Furthermore, this deliverable has covered the topic of applications of GIS and RS in monitoring and maintaining forest area. GIS and RS applications have increased in the last few years, especially in forestry. Some open source as well as commercial platforms are available for performing this task based on different. It also includes the topic of open source and commercial data availability. It is continued with pros and cons of open-source software and further information such as application focus, supporting Operating systems, development platforms, and software license. Rules and criteria for public software licenses have also been described.

It also presents different applications of RS in forest management and their importance. Remote sensing is a powerful tool to monitor forests using different methods and indices. The deliverable includes information about different RS file formats. A bibliographic review has been carried out on the monitoring of marginal lands by using RS techniques.

Finally, it presents some of the ongoing or completed projects which also aimed at using marginal land as carbon sink. Several projects have been presented with a brief description. Furthermore ,some guidelines have been presented in order to understand ML more clearly. The guidelines are a compilation of voluntary recommendations that have been developed for a variety of actors, including companies, agencies, and

stakeholders interested in ML management, and provide guidance on environmental, economic, and social issues.

These guidelines are intended to address the needs outlined in the new EU Forest Strategy 2030, which aims to increase forest cover, restore EU forests, ensure resilient and multifunctional forest ecosystems, combat climate change, increase the rate of carbon sequestration at the European level with the goal of being climate neutral, and support the socio-economic functions of forests in rural areas, boosting the forest bioeconomy within sustainable limits.

1. INTRODUCTION AND GOALS

This document summarises the work done on tasks T5.1 "Best practices MLs monitoring using remote sensing techniques" and T5.4 "Success stories". The main objective of this document is to develop practice strategies for monitoring, management and future utilization of marginal lands using remote sensing techniques. It also gives information about satellite data availability and its sources. To achieve this objective, a literature review of success stories was carried out to define the current state of the art of marginal land management tools.

2. THEORETICAL BACKGROUND

As in the case of methodologies to identify marginal lands, there is no widely accepted method of monitoring and maintenance of recovered marginal lands due to the very different driving factors considered in marginal lands studies (James, 2010; Kang et al., 2013; Shortall, 2013; Sallustio et al., 2018; Ciria et al., 2019). In the specific case of the *MAIL* project, these tasks can be assimilated to the monitoring and maintenance of a forested area. This project has as main objective to trigger marginal lands as carbon sinks, focusing on establishing forest growth on areas that either had forest or lacked it naturally, i.e., carry out a reforestation or an afforestation of a land. Monitoring and sustainable management of marginal lands are crucial in this aspect due to the need to study the evolution of land use change from marginal lands to carbon sinks. As a result, the focus of the success stories and best practices MLs monitoring using remote sensing techniques is to study the sustainable forest management of exploiting forests as carbon sinks. To achieve the objectives of this project, it is necessary to consider that forest products do not sequester carbon forever. The carbon contained in the plants returns to

the atmosphere if they are burned or rotten. In addition, some elements such as fallen leaves quickly rot in the forest, and similarly, wood ends up decomposing and releasing the carbon into the atmosphere after a few decades, or sooner.

To understand the importance of the decisions that should be made planting forests to climate-change mitigation, it is necessary to analyse how the carbon sink will behave in the future, and what actions we have to take to minimise the return of carbon to the atmosphere. Figure 1 shows the forest carbon cycle showing the importance of prioritising win-win strategies to increase forest stocks and timber harvest, implementing measures such as protecting trees from animals or replacing old or low-productivity forests (Bellassen y Luyssaert, 2014). But the implementation of these policies could have negative effects on soil fertility due to the plantation of fast-growing species or on biological diversity of many fungi and insects due to deadwood removal and logging (Bouget et al., 2012; Lassauce et al., 2012). Therefore, when managing the forest mass, it is necessary to consider how the plantations will interact with the environment.
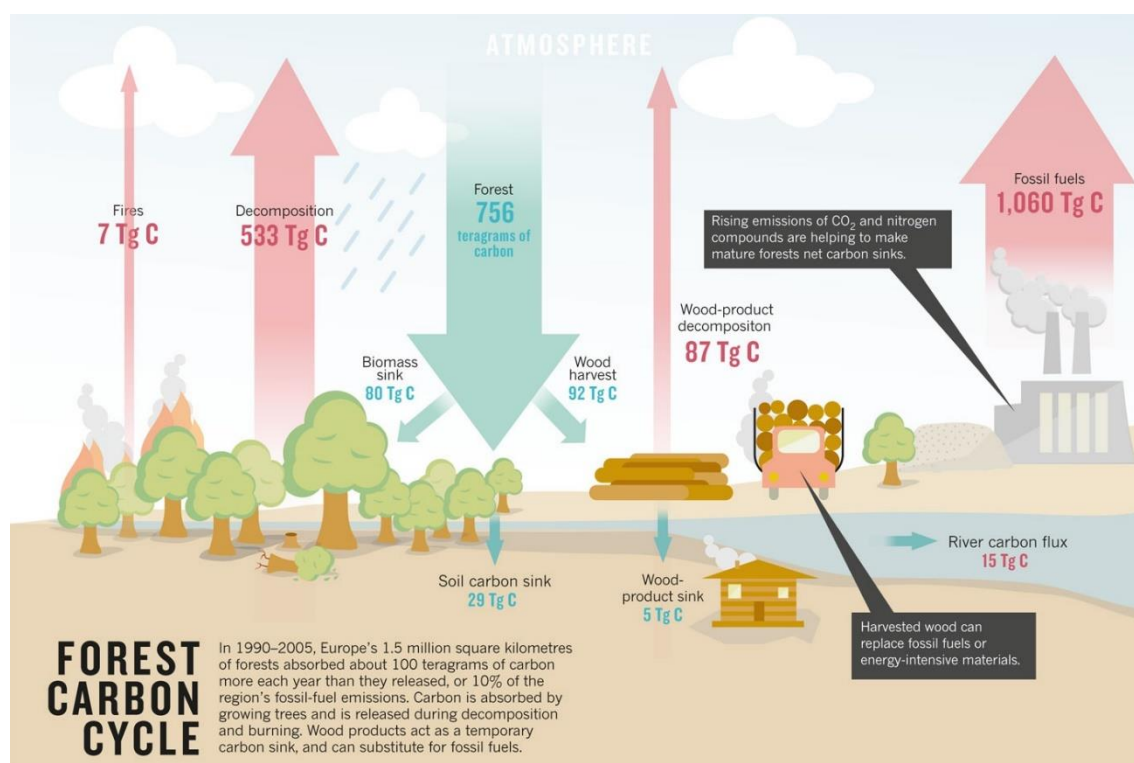

Figure 1. Forest carbon cycle. Source: Bellassen y Luyssaert (2014).

In order to maximise the storage of CO_2 for as long as possible, the following points should be taken into account when creating the system management of marginal lands as a carbon sink:

- Establishment of a unified marginal lands management criteria. There is a need to combine management criteria for all the European countries. This makes mandatory to carry out a planning, considering the regulations in force in each country in the field of forest maintenance.

- Creation of a decision-making system. A land-informatics framework should be used to research, manage, and monitor the marginal lands. This computer system will take decisions based on the variables obtained from marginal lands.

- Collection of variables. To provide feedback to the decision-making system, it will be necessary to take variables from the marginal lands periodically in order to know the ideal time to carry out tasks such as maintenance of the forest mass, cleaning, pruning, etc. These variables, in addition to characterizing the plantation, must also take into account information such as water quality, air quality, soil and land quality or other sustainable assessment tools (Kang et al., 2013).

- Integration of social-economic factors. The use and sale of forestry products generated on recovered marginal land revolve around the market economy, therefore socio-economic factors may be considered in the management of marginal lands.

Within these points, the creation of a decision-making system and the collection of variables is particularly relevant. In order to centralise the decision making in the process of maintaining marginal lands, with the main objective of delaying the return of CO_2 to the atmosphere, some authors such as Kang et al. in 2013 pointed out the importance to rely on computer tools, identifying the essential parts which should have a land-informatics framework applied to the assessment, planning and monitoring of marginal lands Figure 2. This system aims at analysing interrelated land functions and quantitative assessment to create and follow the best management practices to optimise production in marginal lands, considering concerns on environment and sustainability ecosystem. This framework should be supported by software that can deal with all the information provided by the periodic monitoring of the recovered marginal land. Likewise, the software must be capable of making analyses, with the aim of obtaining the necessary parameters in the management of the carbon sinks.
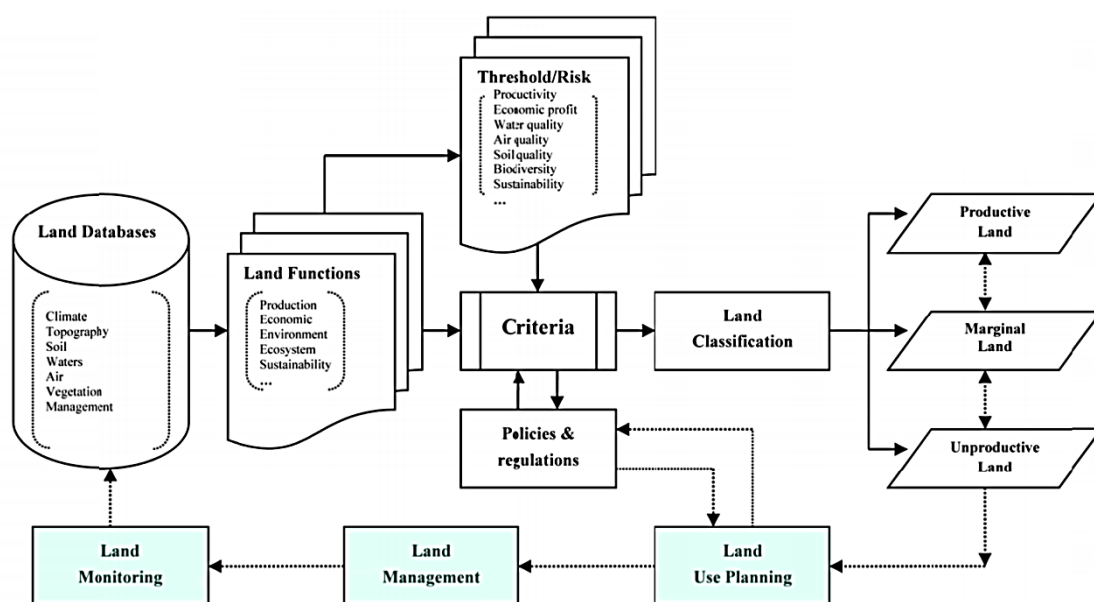
Figure 2. System applied for the assessment, management and monitoring of marginal lands. Source: (Kang et al., 2013)

The management system must be linked to an automated data collection process so that the monitoring of marginal lands is done in a recurrent and automatic way. In recent years, the research involved with defining marginal lands has been based on the combination of spatial tools such as GIS and remote sensing (Nalepa, 2011). In the case of management, especially for the decision-making system and the collection of variables, the GIS tools and the information provided by remote sensing should play a key role. Remote sensing is the practice of obtaining information about the Earth's land through images acquired from an aerial perspective, using electromagnetic radiation, reflected or emitted from the Earth's surface (Campbell y Wynne, 2011). The Geographic Information Systems based on RS are a collection of tools designed to capture, analyse, store, manage, and present geographic or spatial data (Bhat et al., 2011).

To understand the importance of GIS and RS in the maintenance of marginal lands, it is interesting to go deeper into the benefits that these tools can bring us. But first, we should solve the question, what maintenance would recovered marginal lands need?

2.1   Sustainable Management of recovered marginal lands

The process of reforestation or afforestation of marginal lands will force a change in land use. This change in land use, and subsequent management of the carbon sink, must be

carried out through sustainable practices, making it necessary to define the aspects of sustainable forest management.

According to FAO[3] "Sustainable forest management (SFM) is defined as a "dynamic and evolving concept, which aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations". Forests and trees, when sustainably managed, make vital contributions both to people and the planet, bolstering livelihoods, providing clean air and water, conserving biodiversity and responding to climate change.".

A more approximate definition of the term "Sustainable Forest Management", as well as the main policies, criteria and indicators, can be found in the deliverable 5.2 "Guide on the financial social and technical aspects of the sustainable development of MLs, and report on the potentialities of emerging stock exchange markets for carbon transactions and proposed policies". D5.2 presents 45 sustainable forest indicators, 34 quantitative and 11 qualitative. These indicators will be considered in the forest management of the carbon sink. In addition, it shows the need of using tools that allow the analysis of the obtained results, and to make decisions accordingly.

This deliverable aims to improve and monitor soil treatments prior to planting, silvicultural treatments (including clearing of brush), monitoring of tree growth and phytosanitary treatments at different stages of tree growth. The complete improvement of forest management concerns all administrative, economic, legal, social, technical, and scientific aspects related to natural and planted forests, exceeding the objectives of the project.

Once in a previous phase of the project, the production factors have been identified (constituent species in the regeneration of the marginal land, genetic material and its variation, site quality, stem structure, density, etc.), intermediate treatments may be carried out to modulate wood production factors. The main intermediate treatments are the following (Daniel et al., 1982):

- Cleaning and weeding. Removal or killing of over topping competitors that are significantly taller than the desired trees and removal of mainly herbaceous plants and shrubs.
- Pruning. Selective removal of certain parts of a plant, such as branches, buds, or roots.

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[3] http://www.fao.org/forestry/sfm/en/

- Animal pest and disease management. To avoid the deterioration or death of the trees it is necessary to carry out biosecurity practices, detecting the first signs of disease early, in order to isolate the affected individuals and prevent the spread of the disease.

To emphasize this aspect, there are some general guidelines in sustainable forest maintenance. A previous process to the preparation of the soil, and the subsequent planting of the trees that will capture the CO_2, is the selection of the genetic material. In this phase, it is important to take into account factors such as the use of endemic species, which avoid the substitution of pre-existing species in the area to be reforested or afforested. The individuals to be planted should come from nurseries or neighbouring areas with a common climate. An optimal selection of suitable plants would have numerous benefits in the subsequent maintenance of the forest area (e.g. a future replanting of individuals that have not prospered could be avoided). Similarly, an initial aspect to consider is the planting of different tree varieties, with the aim of avoiding the continuity of pests. By diversifying the species to be planted, the risk of the same pest affecting all individuals equally is reduced. In the soil preparation phase, subsoiling should be carried out by making lines to aerate the soil, and in this way, be able to go deep enough to eliminate other species that could compete with the seedlings. Depending on the climate and soil type, between the second and fifth year, control of planting and scrub should be carried out to eliminate competition from the planted trees. From the fifth year onwards, it is considered that the planted trees no longer have competition for nutrients, so normally silvicultural treatments (e.g. pruning or thinning) are started. During this phase it is necessary to carry out a phytosanitary control, trying to promote the use of natural predators of each pest. Phytosanitary control must be carried out specifically for each European region, due to the existence of different pathogens depending on the location. From the tenth year are done clean brush, with the aim of preventing wildfires, focusing on the possible implementation of firebreaks and clean around roads and highways. Finally, the trees should be felled as soon as the biomass growth of the individuals has stagnated.

In order to carry out these phases correctly, the biomass of the forest mass should be monitored, with the aim of identifying the ideal moment to carry out each of the phases described above. These tasks will be carried out mainly in the management task. The main objective of the management tools will be to determine the ideal moment to carry

out cleaning, weeding and pruning, but also to carry out constant monitoring in the detection of possible animal pests and diseases.

Nowadays, computer capacities are in constant evolution and help to create methodologies whose application was unfeasible without a powerful calculation capacity, providing all of them a useful tool for forest management, allowing to take decisions in a fast and objective way. These tools help to be able to manage a forest area in a sustainable way, since, on the one hand, they favour the taking into account of all the criteria (environmental, social, etc.) necessary in a decision making process, and on the other hand, to be able to extract inventory data in a simple, fast and low-cost way (Pérez-Rodríguez et al., 2011).

There are countless software solutions for forest management on the market today. In

Annex III: Forest payment software available in the market. (G2, 2020) some of the payment solutions used by the forest industry can be seen. In the same way, a list of free software used on the forestry industry can be observed in Annex IV: Forest free software examples[4]. These software are mainly based on the management of the forest mass, but not on the collection and treatment of data that allow the monitoring of the forest, that is to say, these software do not carry out a treatment of data obtained from remote sensing.

The management of forest resources requires the integration of a large amount of data referenced in space and time, obtained by remote sensing. In terms of remote sensing and sensor data, we refer to all airborne and satellite instruments designed for Earth observation, ranging from analogue aerial photography to digital satellite instruments, as well as synthetic aperture radar and optoelectronic systems. Including satellite navigation or positioning systems or ground-based remote sensing systems such as ground-based photogrammetry or ground-based laser scanning (Koch, 2011). For the management and analysis of all this information, the GIS is an essential tool in decision-making regarding resource management, being particularly interesting in the valuation of forest resources (inventory, monitoring and determination of the suitability of location) and in resource management (analysis, modelling, and forecasting for management decisions) (Sánchez et al., 1999).

To achieve the sustainable forest management objectives proposed in this task, we will introduce the terms GIS and RS in more depth.

2.2 Marginal lands

2.2.1 Definition of Marginal Lands

In order to define Marginal lands, a literature review was performed using infromation from the Google scholar database and projects associated with Marginal Lands such as SEEMLA (Sustainable exploitation of biomass for energy form Marginal Lands) and MAGIC (Marginal Lands for Growing Industrial Crops). The definition of Marginal lands differs according to the final goal of the study. Generally, a land is termed as marginal land if its output of agricultural production is less than or equal to its production expenses (Ivanina, Roil, & Hanzhenko, 2016). The majority of the approaches are static, ignoring

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[4] http://www.fao.org/sustainable-forest-management/toolbox/tools/es/

the competition that biofuel introduces other uses such as agricultural and environmental conservation (Nalepa, Short Gianotti, & Bauer, 2017).

According to the framework of Geographical science, marginality is primarily caused by unfavourable environmental, cultural, social, political, and economic conditions (Mehretu, Pigozzi, & Sommers, 2000). Many authors have stressed the importance of biophysical (environmental) and socioeconomic factors to define ML. Land evaluation practice has traditionally been developed from the point of agricultural capacity for crop production, largely influenced by soil characteristics (Rossiter, 1996).

Earlier marginal lands were defined as lands with poor soil or other limiting conditions for agriculture, e.g. steep slopes. However, newer approaches include lands where soil productivity was degraded due to human activities such as agriculture or mining (Gerwin et al., 2018; Ivanina & Hanzhenko, 2016; Plieninger & Gaertner, 2011). Characteristics of ML are salinity or sodicity, contamination, compression, acidity, erosion, loss of organic carbon, and overall productivity loss (Gerwin et al., 2018; Ivanina & Hanhenko. 2016; Schröder et al., 2018). There are also some external factors such as high land prices, migration, intensification of agriculture (Strijker, 2005). Figure 3 shows the relative occurrence of each term.
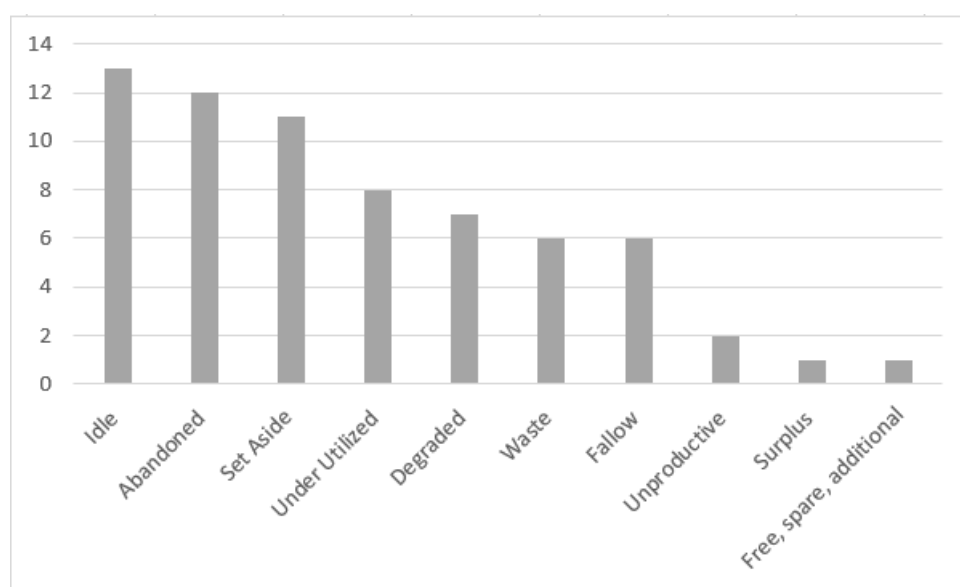

Figure 3: Occurrence of equivalent terms found during literature review. Source: personal compilation/ D2.1.

2.2.2 Categories of Marginal Lands

In Task 2.1, 31 papers were reviewed to define types of ML. There is not a specific definition of Marginal lands or marginality but from the review of papers, the majority of definitions is focused on environmental constraints (20) or economic factors (16) and only 6 use both variables. Socio-economic dimensions of marginality are mentioned only in 3 of the reviewed definitions.
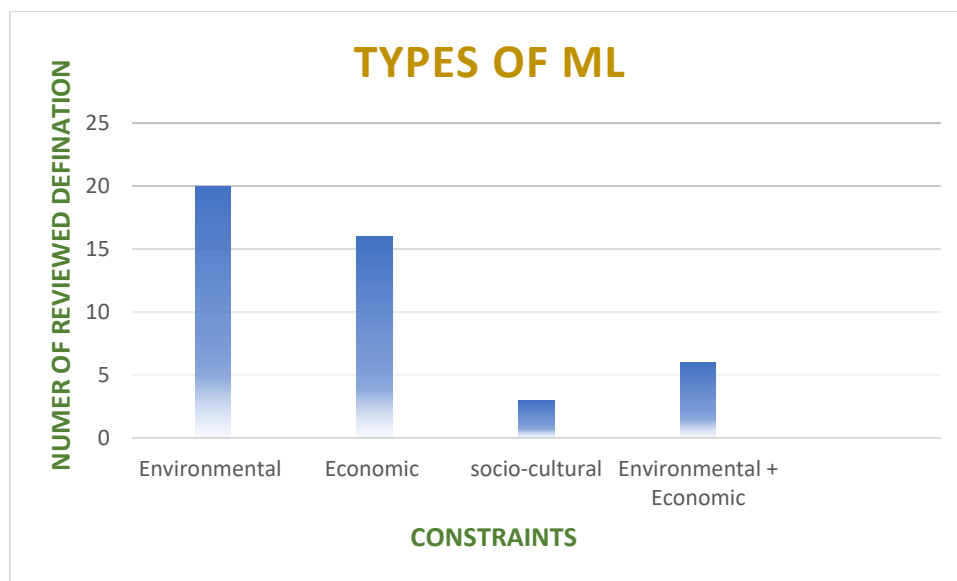
Figure 4: Different constraints to define ML. Source: Personal compilation.

2.2.3 Marginal Lands in Europe

As described in the previous chapter (2.2.1), there is no specific definition of ML but according to European Commission under the articles of the Less Favoured Areas Directives (European Parliament, 2013), marginal lands are roughly classified as Less Favoured Areas (LFA). According to the articles of the aforementioned rule, a region might be designated as a Less Favoured Area in three categories. Each category denotes a specific set of disadvantages that are prevalent to various locations of agricultural lands across Europe and cause significant damage to agricultural land use:

- Mountain areas, which have a short growing season due to high altitude, steep slope at lower height or a combination of both. Mountains are also defined as areas north of the 62nd Parallel.
- Intermediate less favoured areas are those areas in danger of losing agricultural land use and countryside conservation is required. They have the disadvantage of low productive land, a production that is a result of low natural environment

productivity, and a small diminishing population that is mostly dependent on agricultural activity.

- Farming should be sustained in places affected by specific handicaps to conserve or improve the environment, maintain the countryside, preserve the tourist potential of the area, or protect the coastlines.

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 LULUCF regulation establishes a land based approach for accounting the emissions and removals from the sector in five land categories:

1) Afforested and forested land;

2) Managed cropland, grassland and wetland;

3) Managed forest land;

4) Harvested wood products;

5) Natural disturbances.

As a result, not all forest management skills will contribute to the mitigation target (Grassi et al., 2019), therefore carbon stock contribution will differ depending on whether we are talking about previously managed forest areas or afforested and forested land for legal purposes.

2.3 Geographic Information Systems

The first application of the GIS concept was in 1832 when Charles Picquet created a map representing cholera outbreak across 48 districts of Paris. But it was not until 1990 when advances in computers, the availability of multiple software, and the launch of new remote sensing satellites, led to the creation of desktop GIS as we know it now. In this year, the software company Esri released a desktop solution for mapping systems called ArcView. With the expansion of the Internet in the new millennium, there was a wide adoption of GIS and the technology reached government authorities and private enterprise.

The geographic and spatial data generally is represented in the form of maps, which could represent physical, topographic, climate, economic or thematic information, among others. A GIS is composed of hardware, software, technicians, methods and data with multiple information layers that can be used to evaluate relationships among different elements

(Manjrekar y Mane, 2012). GIS is able to create maps, solve problems, develop solutions, integrate information, visualize scenarios and present ideas (Mahapatra y Verma, 2013). The definition of GIS has changed over the years, the following table provides an overview of definitions and meanings of it.

Year	Author	Definition
1979	Dueker	"a special case of information systems where the database consists of observations on spatially distributed features, activities, or events, which are definable in space as points, lines, or areas. A GIS manipulates data about these points, lines and areas to retrieve data for ad hoc queries and analyses."
1981	Ozemoy, Smith and Sicherman	"an automated set of functions that provides professionals with advanced capabilities for the storage, retrieval, manipulation, and display of geographically located data."
1986	Burrough	"a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world."
1986	Devine and Field	"a form of MIS [Management Information System] that allows map display of the general information."
1987	Smith	"a database system in which most of the data are spatially indexed, and upon which a set of procedures operated in order to answer queries about spatial entities in the database."
1988	Parker	"an information technology which stores, analyses, and displays both spatial and non-spatial data."
1988	Cowen	"a decision support system involving the integration of spatially referenced data in a problem-solving environment."
1989	Carter	"an institutional entity, reflecting an organizational structure that integrates technology with a database, expertise and continuing financial support over time."
1989	Koshkariov, Tikunov and Trofimov	"a system with advanced geo-modelling capabilities."
1989	Aronoff	"any manual or computer-based set of procedures used to store and manipulate geographically referenced data."
1995	Clarke	"an automated system for the capture, storage, retrieval, analysis, and display of spatial data."
2001	International Encyclopedia of the Social & Behavioral Sciences	"Geographic information systems (GISs) are defined as software systems, and their relationships to other activities connected with geographic information are reviewed"
2010	United States Geological Survey	"A Geographic Information System (GIS) is a computer system that analyses and displays geographically referenced information"

Year	Author	Definition
2015	DataLB	"A Geographic Information System (GIS) is a computer system used to capture, manage and display geographically referenced information. GIS provides the ability to: visualise where places or features are in proximity to each other, observe patterns in their distribution, and analyse change and relationships in the form of maps and reports."
2017	National Geographic	"A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface."
2019	Esri	"A geographic information system (GIS) is a computer-based tool for mapping and analysing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps."

Table 1. Review of GIS definition. Source: Maguire (1991) and personal compilation.

GIS also plays a key role in forest management, which has a strong link with the management of marginal lands by being able to treat recovered marginal lands as forested areas. In forest management, GIS is used for strategic planning and modelling, map production, fire management, harvest planning or resource management (Sonti, 2015).

The use of GIS, in combination with MCDA (Multi Criteria Decision Analysis), have been the main tool for forest management planning in the last years (Wolfslehner y Seidl, 2010; Uhde et al., 2015). Geographic Information Systems are used, in conjunction with MCDA methods to support decision-makers evaluating multiple criteria to find optimal alternatives applying spatial conditions, such as the identification of marginal lands, against multiple criteria as natural parks or urban areas. MCDA uses decision rules to study the criteria, allowing alternative solutions to be ranked or prioritised (Greene et al., 2011).

In the management section, a desktop GIS will centralise all the information obtained from the monitoring of marginal lands, with the aim of making decisions such as cleaning, pruning, etc. To this end, it will be necessary to carry out a market study of the different software that can be used when creating a GIS project.

2.3.1   Open-source vs commercial

The main question to be answered in finding the right desktop GIS software to meet the needs of a project is the need to use open source or proprietary software.

Proprietary software, or closed source software, is non-free computer software, in which the publisher of the software or another person retains the intellectual property rights, usually the copyright in the source code or the patent rights (Saraswati Experts, 2016).

The criteria for declaring software as open source were established by the Open Source Initiative to determine whether a software license can be labelled with the open source certification mark. The open software must comply with the following criteria (Perens, 1999):

Criteria	Definition
Free redistribution	The license shall not restrict any party from selling or giving away the software as a component of an aggregate software distribution containing programs from several different sources.
Source code	The program must include source code and must allow distribution in source code as well as compiled form.
Derived works	The license must allow modifications and derived works and must allow them to be distributed under the same terms as the license of the original software.
Integrity of the author's source code	The license may restrict source-code from being distributed in modified form only if the license allows the distribution of "patch files" with the source code for the purpose of modifying the program at build time.
No discrimination against persons or groups	The license must not discriminate against any person or group of persons.
No discrimination against fields of endeavour	The license must not restrict anyone from making use of the program in a specific field of endeavour. For example, it may not restrict the program from being used in a business, or from being used for genetic research.

Criteria	Definition
Distribution of license	The rights attached to the program must apply to all to whom the program is redistributed without the need for execution of an additional license by those parties.
License must not be specific to a product	The rights attached to the program must not depend on the program's being part of a software distribution.
License must not restrict other software	The license must not place restrictions on other software that is distributed along with the licensed software.
License must be technology-neutral	No provision of the license may be predicated on any individual technology or style of interface.

Table 2. Open Source definition. Source: (Perens, 1999)**.**

Open source software offers greater user freedom, reducing product costs, but more in-depth analysis applied to GIS is needed. In order to know if the benefits of open source impact on a direct improvement of the project, or if the payment of proprietary software is profitable due to higher productivity and an improvement of the results.

In this sense, it is necessary to know that open source software is regulated under different open source licenses. An open source license is a type of license for software and other products that allows the use, modification and/or sharing of the source code or the design under defined conditions (Perens, 1999). This allows end-users and commercial companies to review and modify the software for their own curiosity, customization or troubleshooting needs. Open source licenses may have some restrictions, in particular regarding the expression of respect for the source of the software, such as the requirement to preserve the name of the authors and a copyright statement within the code, or the requirement to redistribute the licensed software only under the same license. Open source software licenses are governed by the Open Source Initiative, which has approved over one hundred licenses (Open Source Iniciative, 2020). In order to make a comparison between the different GIS software licenses, two tables are shown below. Table 3. Description of the license terms used in the comparison of open source licenses. Source: (European Comission, 2019) shows the description of the different terms analysed in the comparison, while Table 4. Comparison of the ten most used open source licenses. Source: Join up Licensing

Assistant of the European Commission, (MICHAELI, 2016) and personal compilation. shows a comparison of the ten most used licenses.

License term		Description
Can	Use/reproduce	Ability to use, copy/reproduce the work freely in unlimited quantities
	Distribute	Ability to distribute the work to third parties freely, in unlimited quantities
	Modify/merge	Ability to modify/combine the work with others and create derivatives
	Sublicense	Ability to license the work, including possible modifications (without changing the licence if it is copyleft or share-alike)
	Commercial use	Ability to make use of the work for commercial purposes or to license it for a fee
	Use patents	Rights to practice patent claims of the software owner and of the contributors to the code, in so far these rights are necessary to make full use of the software
	Place warranty	Ability to place additional warranty, services, or rights on the software licensed (without holding the software owner and other contributors liable for it)
Must	Incl. Copyright	Describes whether the original copyright and attribution marks must be retained
	Royalty free	In case a fee (i.e. contribution, lump sum) is requested from recipients, it cannot be royalties (depending on the use)
	State changes	Source code modifications (author, why, beginning, end) must be documented

License term		Description
Cannot	Disclose source	The source code must be publicly available
	Copyleft/Share a.	In case of (re-) distribution of the work or its derivatives, the same licence must be used/granted: no re-licensing
	Include licence	Include the full text of the licence in the modified software.
	Rename modifs.	Obligation to rename the work in case a modified/derivative version is distributed
	Hold liable	No recipient may charge the software owner or contributors for direct or indirect damages. This is a frequent clause in open licences
	Use trademarks	No allowance of using the original licensor or contributors' names, trademarks, or logos (i.e. for advertisement, promotion)
Compatible	Permissive	The licence authorises reusing or merging the covered code in software covered any other licence (free/libre or proprietary)
	GPL	The licence authorises reusing or merging the covered code in software covered by the GNU/GPL
	Other copyleft	The licence is interoperable with other copyleft licences and authorises reusing or merging the covered code in software covered by these other copyleft licences
	Linking freedom	"Linking for interoperability" with other software has no impact on the licensing condition of the other software

License term		Description
	For software	The licence was designed for the distribution of software
Support	Strong Community	The licence is supported by a solid community: licence steward has a website as a legal support addressing questions/publishing FAQs or cases
	OSI approved	The licence is approved by the Open Source Initiative, as compliant with the Open Source Definition (OSD)
	FSF Free/Libre	The licence is considered as Free/Libre by the Free Software Foundation

**Table 3. Description of the license terms used in the comparison of open source
licenses. Source:** (European Comission, 2019)**.**

The 10 most used licenses are the following, ordered according to their use from highest to lowest: MIT (Massachusetts Institute of Technology) license / X11 license, GNU General Public License 3.0, Apache License 2.0, GNU General Public License 2.0, BSD 3, LaTeX Project Public License, Microsoft Public License, BSD 2 and zlib/libpng. Of this list, the MIT license stands out, which is a short and very popular license, supported by a strong community. If software uses this license, the user can do whatever wants if the original copyright and license notice is included on any copy of the software.

On the other hand, the GNU GPL 3.0 license is also supported by a strong community. Using this license, the user can copy, distribute, and modify the software as long as the changes in the source files are recorded. Any derivatives included must also be available under the GPL 3.0 along with compilation and installation instructions. The main problem with this license is that it is not compatible with any other license.

Another license that is widely supported by the developer community is Apache 2.0. This license allows you to do everything with the software if the required notices are included.

The table below compares these licenses, with the remaining seven most used:

License	Author	Publication date	Can	Must	Cannot	Compatible	Support	Distribution share
MIT license / X11 license	MIT	1988	Use/reproduce, Distribute, Modify/merge, Sublicense, Commercial use	Incl. Copyright, Include licence	Hold liable	Permissive, GPL, Other copyleft, Linking freedom, For software	Strong Community, OSI approved, FSF Free/Libre	25%
GNU General Public License (GPL) 3.0	Free Software Foundation	2007	Use/reproduce, Distribute, Modify/merge, Commercial use, Use patents, Place warranty	Incl. Copyright, State changes, Disclose source, Copyleft/Share a., Include licence	Hold liable, Use trademark	GPL, For software	Strong Community, OSI approved, FSF Free/Libre	19%

License	Author	Publication date	Can	Must	Cannot	Compatible	Support	Distribution share
Apache License 2.0	Apache Software Foundation	2004	Use/reproduce, Distribute, Modify/merge, Sublicense, Commercial use, Use patents, Place warranty	Incl. Copyright, State changes, Disclose source, Include licence	Hold liable, Use trademark	Permissive, GPL, Other copyleft, Linking freedom, For software	Strong Community, OSI approved, FSF Free/Libre	15%
GNU General Public License 2.0	Free Software Foundation	1991	Use/reproduce, Distribute, Modify/merge, Commercial use, Place warranty	Incl. Copyright, State changes, Disclose source, Copyleft/Share a.	Hold liable, Sublicence	For software	Strong Community, OSI approved, FSF Free/Libre	15%
BSD 3	University of California	-	Use/reproduce, Distribute, Modify/merge, Sublicense, Commercial use	Incl. Copyright, Include licence	Hold liable, Use trademark	Permissive, GPL, Other copyleft, Linking freedom, For software	Strong Community, OSI approved, FSF Free/Libre	6%

License	Author	Publication date	Can	Must	Cannot	Compatible	Support	Distribution share
LaTeX Project Public License	LaTeX project	-	Use/reproduce, Distribute, Modify/merge, Sublicense, Commercial use	Incl. Copyright, State changes, Disclose source	Hold liable, Use trademark	Permissive, GPL, Other copyleft, Linking freedom, For software	OSI approved, FSF Free/Libre	6%
Microsoft Public License	Microsoft	-	Use/reproduce, Distribute, Modify/merge, Commercial use, Place warranty	Incl. Copyright, Disclose source, Copyleft/Share a., Include licence	Hold liable, Use trademark	Other copyleft, Linking freedom, For software	OSI approved, FSF Free/Libre	5%
BSD 2	University of California	-	Use/reproduce, Distribute, Modify/merge, Sublicense, Commercial use	Incl. Copyright, Include licence	Hold liable	Permissive, GPL, Other copyleft, Linking freedom, For software	Strong Community, OSI approved, FSF Free/Libre	3%

License	Author	Publication date	Can	Must	Cannot	Compatible	Support	Distribution share
zlib/libpng	Jean-Loup Gailly and Mark Adler	-	Use/reproduce, Distribute, Modify/merge, Commercial use	Incl. Copyright, Rename modifs.	Hold liable	Permissive, GPL, Other copyleft, Linking freedom, For software	OSI approved, FSF Free/Libre	1%
Eclipse Public License 2.0	Eclipse Foundation	2017	Use/reproduce, Distribute, Modify/merge, Sublicense, Commercial use, Use patents	Incl. Copyright, Royalty free, Disclose source, Copyleft/Share a., Include licence	Hold liable, Use trademark	GPL, Linking freedom, For software	Strong Community, OSI approved, FSF Free/Libre	1%

Table 4. Comparison of the ten most used open source licenses. Source: Join up Licensing Assistant of the European Commission, (MICHAELI, 2016) **and personal compilation.**

2.3.1.1 Commercial desktop GIS software pros and cons

The advantages of using desktop GIS programs are mainly that they are user-friendly, allowing a wide variety of spatial analysis and having great technical support, as well as a large community.

One of the most outstanding features of proprietary software is its ease of use, in addition to the low error rate compared to open source software. One of the most outstanding examples in this regard is ArcGIS. ArcGIS has an intuitive and easy-to-use interface. This ease of use is coupled with a variety of tools for performing spatial analysis, being designed to quickly perform everything from network analysis, to land-use analysis. However, when dealing with projects by companies or institutions, one of the most positive aspects is the technical support. Technical support in desktop GIS is usually performed by professionals based in all regions. This support is also added to the existence of extensive FAQ sections, email assistance or over-the-phone inquiries. In the case of desktop GIS, ArcGIS has 43% of the market (Alban, 2015), which allows for a large community of users to share their experiences and help. In addition, proprietary file formats as shapefile (developed by Esri) are de facto standard in the industry.

In contrast, the two most notable disadvantages of using proprietary software are the limitation of user development and cost.

Although they have a large number of spatial analysis and geoprocessing capabilities, some projects require specific development of tools to carry them out. In most cases, proprietary software prevents the user from developing tools, forcing him to work within the limits of the software. This is added to the cost of acquiring and maintaining the software, which is normally the main obstacle faced by users to use this type of software.

2.3.1.2 Open-source desktop GIS software pros and cons

The most important benefits of using open-source desktop GIS are the cost, the possibility of development, its interoperability, and the operation in different operating systems.

The possibility of developing GIS applications is one of its greatest assets. Although open-source software does not have an interface as intuitive as commercial software, it does allow the development of personalized and specific applications. This allows developers and users to adapt and develop applications to meet exact specifications, without having to pay software license fees. Similarly, another benefit of using open-source software is the compatibility with different operating systems. Typically,

proprietary GIS software is developed only for Windows, while open-source GIS works on Windows, Mac, Linux and more. However, the great advantage of open-source software over proprietary software is its zero cost, which implies a great reduction in the cost of development for users, developers, companies, and institutions.

On the other hand, some of the most notable disadvantages of using free software are the lack of development of some tools and inconsistent technical support.

While open-source mapping programs such as QGIS have many built-in tools for statistical analysis, spatial analysis, and geoprocessing, some of these tools are not as refined as in proprietary software, causing worse than expected results or longer processing time. On the other hand, regarding the technical support that open-source software offers, in practice most applications are based on the use of online FAQs and manuals, as well as online forums such as Stack Overflow, which are a great place for users of open source mapping software to look for information and make voice queries. Virtually all open-source software has no officially established technical support lines.

2.3.1.3 Open-source desktop GIS projects

In recent years, the world of free and open-source geospatial software has undergone some important changes. For example, the FreeGIS.org website lists 330 GIS-related projects. In recent years the use of GIS has increased considerably, which has led to the emergence of free and open-source GIS software, where researchers, users and developers have enhanced these systems with their contributions to their development, thus implementing tools that can help solve specific needs for the use of spatial data. Currently, the most used free and open-source software are GRASS, QGIS, SAGA, gvSIG, uDig and Kosmo.

- GRASS: Developed by the United States Army in the 1990s. It is free and open-source software that can even be used as an application for other software such as QGIS and R geostatistics. It has wide potential for work on raster and vector data, and even animations can be created; it has a friendly interface.
- QGIS: It is one of the most popular free software because of the development it has had since its release in 2002, initially known as Quantum GIS. It has a wide variety of formats to work with. One of its features is that plug-ins can be incorporated, which allows a great variety of processes to be carried out with both vector and raster data; as well as with WMS and WFS servers. Its download is simple, and its interface is very friendly.

- SAGA: Named as System for Automated Geoscientific Analysis, it was developed by a team of researchers from the Department of Physical Geography at the University of Göttingen, Germany, in 2001. This software predominates in the treatment of raster data, having also 3D functionalities.

- gvSIG: It started in Valencia, Spain in 2003. The gvSIG Desktop application was the first version that was developed from the gvSIG project, currently, it has its mobile version, and has developed a range of tools for consultation, design, geoprocessing, in addition to a 3D extension.

- uDig: It is an open project that began in 2004. One of its main features is the support of data from Internet servers. It has great attributes to work with data from WMS and WFS servers, in addition to viewing, editing, and printing files, databases such as Oracle, SDE and PostGIS. It uses Geotools as input and output libraries of data, which will allow working with many formats.

- Kosmo: It started in 2007, distributed under the GPL license and developed from the JUMP platform. It works with shapefile, TIFF, GEOTIFF, ECW, MrSID, BMP, GIF, JPG, PNG files. It has a user-friendly interface and has the implementation of tools such as Kosmo Server (raster and vector cartography server); Kosmo Desktop (consultation, editing and analysis); Kosmo Lightweight Client (cartographic browser for connection to services based on OGC standards) and Kosmo Mobile (for mobile devices).

A comparison of the most used free and Open-Source desktop GIS is shown in Table 5. Comparison of the most used Free and Open Source Desktop GIS projects. Source: Steiniger and Bocher (2009) and personal compilation.

Project (year)	Application focus	User-level	Supported operating systems	Development platform	Development by	Software license
GRASS (1982)	Analysis and scientific visualisation, Cartography, Modelling, and simulation	Experienced, …, research	Windows, Linux, MacOS, Solaris	C, Shell, Tcl/Tk, Python	Research Institutes, Universities, Companies, Volunteers worldwide	GPL
QGIS (2002)	Analysis and scientific visualisation, Cartography, Modelling, and simulation	novice, …, research	Windows, Linux, MacOS, Android, BSD	C++, Qt4, Python	Universities, Companies, Volunteers worldwide	GPL
SAGA (2001/2)	Analysis, Modelling, Scientific visualisation	novice, …, research	Windows, Linux	C++	Universities	GPL
gvSIG (2003)	Analysis and scientific visualisation, Cartography, Modelling, and simulation	novice, …, research	Windows, Linux, MacOS, Android	JAVA	Companies, Universities, Government	GPL
uDig (2004/5)	Viewing, Editing, Analysis	novice, …, research	Windows, Linux, MacOS	JAVA (Eclipse RCP)	Companies, Organisations, Volunteers	Eclipse
Kosmo (2005)	Viewing, Editing, Analysis	novice, …, expert	Windows, Linux	JAVA	Companies (project driven, utilities, etc.), Government	GPL

Table 5. Comparison of the most used Free and Open Source Desktop GIS projects. Source: Steiniger and Bocher (2009) and personal compilation.

2.3.1.4 Commercial desktop GIS packages

Commercial GIS software is currently the most used globally, due to various factors explained above as 24/7 support or the use of proprietary formats. These facts make that most companies and GIS users around the world adopt commercial software. In this sense, the most used software programs are ArcGIS, Geomedia, MapInfo, Global Mapper, Bentley Map, TerrSet and AutoCAD Map 3D.

- ArcGIS: Esri burst onto the geospatial scene in the 1970s. Today he is the market leader in commercial GIS software. ArcGIS is a software package formatted by ArcGlobe and ArcScene (regional 3D visualization), ArcEarth (global 3D visualization) and ArcMap, used for cartographic production, analysis, and visualization (Price, 2010). The main potential of ArcGIS is its extensions, which allow any cartographic task to be carried out quickly and efficiently. The extensions are 3D Analyst, Geostatistical Analyst, Maplex, Network Analyst, Schematics, Spatial Analyst, Tracking Analyst y ArcScan.

- Geomedia: This software was created by Intergraph and is currently developed by Hexagon Geospatial Geomedia has a 40-year history in the GIS industry, being ArcGIS' main rival for years. Geomedia is a commercial GIS software package that provides advanced data management, visualization, analysis, and mapping tools. One of its main features is the speed of visualization of three-dimensional models, also including intelligent data capture and validation tools, cadastral data management, 3D point cloud treatment capability or a mobile application called MapWorks, among others.

- MapInfo: Produced by Pitney Bowes Software (formerly MapInfo Corporation) is used for mapping and location analysis. MapInfo allows to analyse, visualise, edit, and produce data to discover associations, patterns, and tendencies, exploring spatial data to symbolize features and create maps.

- Global Mapper: Global Mapper is developed by Blue Marble Geographics. Global Mapper handles both vector, raster, and elevation data, and provides viewing, conversion, and other general GIS features (Blue Marble Geographics, 2020).

- Bentley Map: Bentley Map creates, analyses, and shares business and engineering information that is adapted to different geospatial and engineering workflows (Bentley Systems, 2020). It has five different packages: Bentley Map PowerView (2D/3D map viewing and modification), Bentley Map (2D/3D geospatial information editing, analysis, and management, map finishing, and

advanced cadastral information management), Bentley Map Enterprise (2D/3D geospatial information editing, analysis, and management, and raster images), Bentley Map Mobile (GIS data viewing on smartphones), Bentley Map Mobile Publisher (geospatial data publishing).

- TerrSet: This software was created by Clark Labs. TerrSet (formerly IDRISI) has a set of 300 GIS processing tools, mainly oriented to the processing of raster data. This software has different complements such as the Land Change Modeler that models landscape trends to support decisions, the Habitat and Biodiversity Modeler that shows patterns for habitat assessment or different complements focused on climate change, ecosystem, and Earth trends.

- AutoCAD Map 3D: AutoCAD Map 3D is an AutoCAD-based map processing software package produced by Autodesk, first released in 1996. This software is an AutoCAD package with several features dedicated to the creation, theming, and review of maps. This software can be combined with other Autodesk products such as MapGuide Open Source for web publishing, Raster Design for raster map processing or AutoCAD Civil 3D for 3D territory projects.

A comparison of the most used commercial desktop GIS is shown in the table below.

Project (year) [Developer]	Application focus	User-level	Supported operating systems	Development platform
ArcGIS (1999) [Esri]	Analysis and scientific visualisation, Cartography, Modelling, and simulation	novice, …, research	Windows, Android, iOS	Python
Geomedia (2015) [Intergraph]	Analysis and scientific visualisation, Cartography, Modelling, and simulation	novice, …, research	Windows, Android	-
MapInfo (1986) [Pitney Bowes Software]	Viewing, Editing, Analysis	novice, …, research	Windows	-
Global Mapper (1995) [Blue Marble Geographics]	Analysis and scientific visualisation, Cartography, Modelling, and simulation	novice, …, research	Windows	-
Bentley Map (-) [Bentley Systems]	Viewing, Editing, Analysis	novice, …, research	Windows, Android	-

Project (year) [Developer]	Application focus	User-level	Supported operating systems	Development platform
TerrSet (1987) [Clark Labs]	Analysis and scientific visualisation, Cartography, Modelling, and simulation	novice, …, research	Windows	-
AutoCAD Map 3D (1996) [Autodesk]	Viewing, Editing, Analysis	novice, …, research	Windows	-

Table 6. Comparison of the most used commercial Desktop GIS projects. Source: Personal compilation.

2.4 Remote Sensing

The history of remote sensing begins in 1850 when Gaspard-Félix Tournachon captured the first aerial photograph using a hot-air balloon, through 1957, when the Soviet Union put Sputnik 1 into orbit, to 2020, when nearly 90,00 artificial satellites have orbited the Earth (United States Air Force's 18th Space Control Squadron, 2020) and a constellation of Sentinels watch over the planet. Currently, there are 839 satellites in orbit dedicated to Earth observation (Union of Concerned Scientifics, 2019). During the last decades, the world has seen significant and rapid progress in the field of remote sensing, and therefore, in geospatial information acquisition and mapping (Sajjad y Kumar, 2019).

Remote sensing systems are the main source of spatiotemporal information for GIS. Thanks to remote sensing, a wide range of environmental parameters can be measured including land use, land cover, vegetation, surface temperatures, geology, soil types or surface elevation. Specifically, RS has changed the forest management paradigm in the last decades, being not feasible a forest inventory that does not rely on remote sensing information to characterise forest resource information for tactical, strategic, and operational planning (White et al., 2016).

Currently, there are several free GIS data sources that provide geospatial information for land monitoring. In terms of free GIS data sources, the following table shows the most widely used.

Data source	Description	Advantages	Data types
Esri Open Data Portal	ESRI's open data portal allows the download of vector and raster information from different categories such as commerce, socio-demographic data, economy, education, culture, government, health, science, environment, transport, or infrastructure.	It has more than 250,000 open data sets from over 5,000 organizations worldwide.	Files are in spreadsheet, KML, shapefile. API's are OGC WMS, GeoJSON and GeoService.
Natural Earth Data	Natural Earth Data is a public domain map available at scales of 1:10,000,000, 1:50,000,000 and 1:110,000,000. It has vector and raster data, with cultural and physical information available.	Download global free GIS data in public domain Supported by the North American Cartographic Information Society (NACIS).	Cultural, physical and raster data. Quick start kits with all the essential stylized layers.
USGS Earth Explorer	EarthExplorer provides online search, navigation display, metadata export, and downloading of earth science data from the U.S. Geological Survey (USGS)	Global satellite imagery The user interface is user-friendly and allows filtered searches of the information.	Raster data (GEOTIFF) from Landsat, Sentinel-2, NASA's ASTER or SRTM
OpenStreetMap	OpenStreetMap is a collaborative project to create editable and free maps. The maps are created using geographic information captured by users using mobile GPS devices, orthophotographs and other free sources.	Free, detailed vector data with different levels of accuracy and completeness	High spatial resolution cultural vector data, such as buildings, roads, parks, etc.
NASA's Socioeconomic Data and Applications Center (SEDAC)	SEDAC is one of the Distributed Active Archive Centers in the Earth Observing System Data and Information System of the U.S. National Aeronautics and Space Administration.	SEDAC provides global socio-economic data on 15 different topics.	Layout maps
Open Topography	OpenTopography provides high-resolution topographic data. This data source has collected over 300 high-resolution data sets, in point cloud, mostly LiDAR, and raster formats.	From its search window it is possible to find LiDAR data available for free.	Point cloud LiDAR information. If LiDAR is unavailable, coarse global DEMs are available for download.

Data source	Description	Advantages	Data types
UNEP Environmental Data Explorer	United Nations Environment Programme (UNEP) is the authoritative source for UN data. It provides more than 500 variables such as freshwater, climate and health.	Spatial and non-spatial data on a variety of themes. Display maps, graphs, and tables on-the-fly.	Themes include population, forests, emissions, disasters, and GDP for spatial and non-spatial data.
NASA Earth Observations (NEO)	The Earth Observation System is a NASA program that comprises a series of artificial satellite and scientific instrument missions in Earth orbit designed for long-term observations of the Earth's surface, biosphere, atmosphere, and oceans	Constant updates ensuring timely global climate information. Accessible in a variety of GIS formats.	Raster information of atmosphere, energy, land, life and ocean GIS data.
Sentinel Satellite Data	The Copernicus Open Access Hub enables the download of information collected by the European Space Agency's Sentinel missions.	The Open Access Hub provides complete, free, and open access to Sentinel-1, Sentinel-2, Sentinel-3 and Sentinel-5P user products.	Raster data information.
Terra Populus	Terra Populus integrates population and environmental data from over 160 countries around the world.	User-friendly interface with customized temporal data delivery.	Environmental data describing land cover, land use, and climate.
FAO GeoNetwork	GeoNetwork's open source allows easy sharing of geographically referenced thematic information between different organizations. It aims to enhance global sustainable development by providing information on global agriculture or food security and fisheries.	Search wide range of categories and filter by country.	Agriculture, fisheries, land resource GIS data.
EOBrowser	EO Browser makes it possible to browse and compare full resolution images from all the data collections provided by Sentinal Hub.	It allows to visualise and compare data from many different satellites.	Raster data information.

Data source	Description	Advantages	Data types
Sentinel Playground	Sentinel Playground makes use of Sentinel Hub technology to provide full-resolution Sentinel-1, Sentinel-2, Landsat 8, DEM, and MODIS imagery, as well as EO data products, easier to find and explore.	To locate the most up-to-date imagery of current events (such as forest fires), monitor droughts, download a nice-looking poster, or simply learn how Earth observation products are made.	NDVI, Moisture Index, SWIR, NDWI, NDSI, Classification map in JPG and GEOTIFF format

Table 7. Description, advantages, and data types of the most widely used free remote sensing and GIS data source. Source: GISGeography.com (2020) and personal compilation.

All these data sources provide a large amount of information free of charge and accessible to everyone who needs powerful software. There are currently many specific software applications dedicated to the processing of remote sensing data. Remote sensing packages use specific file formats that contain sensor image data, georeferencing information, or sensor metadata, among other specific information provided by the sensor in charge of obtaining the data. The most popular remote sensing file formats are:

- ECW: Proprietary format based on wavelet compression to reduce the size file. It was developed by Earth Resource Mapping, currently it is owned by Hexagon AB. This format efficiently compresses very large images with fine alternating contrast while preserving their visual quality.

- GRID: Proprietary format developed by Esri. This format is supported by most remote sensing packages. This format defines the geographic space as a grid of equal size arranged in rows and columns, in other words, x and y coordinates.

- IMG: Proprietary format developed by ERDAS which provides a framework for integrating sensor data and images from many sources.

- JPEG 2000: This format is an image compression standard and coding system. This format is based on discrete wavelet transforms to compress the image.

Proprietary and free software have been used to process all this huge information and all this variety of formats, as in the case of GIS. For this reason, it is necessary to go into

this section again, analysing the different software that can process the information from remote sensing.

2.4.1 Access to satellite images data

Satellite data is becoming more and more accessible. Today satellite data can be available to anyone with ample of data access on several platforms. It is widely used for military or scientific community. Numerous websites provide high-resolution satellite and aviation data, as well as two- and three-dimensional maps of the communication network, geography, and the important locations or interesting spots. Images can be downloaded according to an individual's requirement and visualised. Here, both free and commercially available satellite data providers have been listed.

While talking about satellite data, there are three main parameters: Spatial, temporal, and spectral resolution. Spatial resolution is the pixel size of an image. It is also a measure of the smallest object that can be picked out from surrounding objects. Temporal resolution is the time taken by satellite to visit same area again. Spectral resolution is the ability of satellite sensor to measure the specific wavelength of the electromagnetic spectrum.

2.4.1.1 *Very high spatial resolution*

 Typical data with Very High Resolution (VHR) offer a spatial resolution of more than 5 meters, with a perceptible tendency nowadays to glide below one meter. This specificity makes VHR data similar to aviation data. Optical VHR imaging is performed in only a few spectral ranges of visible and near infrared radiation. VHR data acquisition is the domain of commercial companies. They usually offer their customers only low-level products, i.e. not interpreted as thematic products.

Sensor	Website	Free	Paid
ALI	http://earth.esa.int/dataproducts/	☒	
ALOS	https://gportal.jaxa.jp/gpr/notice/case/view/1092	☒	☒
AVIRIS	http://earth.esa.int/dataproducts/	☒	
ALOS-PRISM	http://earth.esa.int/dataproducts/	☒	☒
Cartosat-2	http://www.euromap.de/		☒

Sensor	Website	Free	Paid
	http://www.nrsc.gov.in/		☒
Cartosat-2A	http://www.nrsc.gov.in/		☒
Cartosat-2B	http://www.nrsc.gov.in/		☒
CBRES 2B-HRC	http://www.satimagingcorp.com/		☒
EROS A	http://www.smallgis.pl/		☒
EROS B	http://www.smallgis.pl/		☒
Formosat-2	http://www.spotimage.com/		☒
	http://www.geosystems.pl/		☒
GeoEye-1	http://www.geoeye.com/		☒
GeoEye-2	http://www.geoeye.com/		☒
HRSC-A	http://earth.esa.int/dataproducts/		☒
Icons	http://www.geoeye.com/		☒
IRS-P5	http://www.euromap.de/		☒
	http://www.nrsc.gov.in/		☒
IRS-P6/LISS-4	http://www.euromap.de/		☒
	http://www.geosystems.pl/		☒
	http://www.nrsc.gov.in/		☒
IRS-1C/1D PAN	http://www.euromap.de/		☒
Kompsat-2	http://www.spotimage.com/		☒
	http://www.geosystems.pl/		☒
OrbView-2	http://www.geoeye.com/		☒
SPOT-5	http://www.spotimage.com/		☒
	http://www.geosystems.pl/		☒
QuickBird	http://www.geoeye.com/		☒

Sensor	Website	Free	Paid
	http://www.smallgis.pl/		☒
RapidEye	http://www.rapideye.de/		☒
	http://www.nrsc.gov.in/		☒
WorldView -1	http://www.digitalglobe.com/		☒
	http://www.smallgis.pl/		☒
WorldView - 2	http://www.digitalglobe.com/		☒
	http://www.smallgis.pl/		☒
WorldView - 3	http://www.digitalglobe.com/		☒
	http://www.smallgis.pl/		☒
WorldView - 4	http://www.digitalglobe.com/		☒
	http://www.smallgis.pl/		☒
Dove Cubasat	https://www.planet.com/		☒
Skysat	https://www.planet.com/		☒

Table 8. Optical data (visible and infrared radiation) for very high resolution satellite data

Sensor	Website	Free	Paid
TerraSAR-X/ TanDEM-X	http://infoterra.de/		☒
	http://www.geosystems.com.pl		☒
COSMO-SkyMed	http://www.e-geos.it/		☒
	http://www.cosmo-skymed.it/		☒
RadarSat-2	http://www.radarsat2.info/		☒
	http://gs.mdacorporation.com/		☒
	http://www.geosystems.pl/		☒

Table 9. Radar data for very high resolution satellite data

2.4.1.2 High spatial resolution

The best example of High-Resolution (HR) data imaging sensors are a series of Landsat satellites. They are characterized by a spatial resolution of over 30-50 meters, with a time resolution of several days and several spectral channels, including visible radiation, near infrared and thermal infrared. Satellites providing HR data are both scientific and government endeavours, as well as (especially in recent decades) commercial ventures. Users are offered primarily uninterpreted data, but also thematic data (land cover maps, radiation temperature maps, terrain deformation maps, etc.). Optical and radar HR images are the most sought-after satellite data.

Sensor	Website	FREE	PAID
Sentinel – 2	http://earth.esa.int/dataproducts/	☒	
ASTER	https://wist.echo.nasa.gov/	☒	☒
	http://imsweb.aster.ersdac.or.jp/	☒	☒
ALOS-AVNIR2	http://earth.esa.int/dataproducts/		☒
CBRES 1-2 / 2B	http://www.satimagingcorp.com/		☒
CBERS-2	http://www.satimagingcorp.com/		☒
ChrisProbaM1	http://earth.esa.int/dataproducts/	☒	☒
DMC	http://www.dmcii.com/		☒
EO-1 Hyperion	http://earthexplorer.usgs.gov/	☒	
EnMap	http://earth.esa.int/dataproducts/	☒	
Hyperion	http://earth.esa.int/dataproducts/	☒	
IRS-P6 / LISS-3	http://www.nrsc.gov.in/		☒
	http://www.euromap.de/		☒
	http://earth.esa.int/dataproducts/	☒	☒

IRS-P6 / AWIFS	http://www.nrsc.gov.in/		☒
	http://www.euromap.de/		☒
	http://earth.esa.int/dataproducts/	☒	☒
IRS-1C / 1D LISS3	http://www.nrsc.gov.in/		☒
	http://www.euromap.de/		☒
Landsat	http://earthexplorer.usgs.gov/	☒	
SPOT 1-5	http://www.spotimage.com/		☒

Table 10. Optical data (visible and infrared radiation) for high resolution satellite data

Sensor	Website	FREE	PAID
Sentinel – 1	http://earth.esa.int/dataproducts/	☒	
RadarSat-2	http://www.radarsat2.info/		☒
	http://gs.mdacorporation.com/		☒
	http://www.geosystems.pl/		☒
ALOS-PALSAR	http://earth.esa.int/dataproducts/	☒	☒
TerraSAR-X / TanDEM-X	http://infoterra.de/		☒
	http://www.geosystems.com.pl		☒
COSMO-SkyMed	http://www.e-geos.it/		☒
	http://www.cosmo-skymed.it/		☒
ENVISAT-ASAR	http://earth.esa.int/dataproducts/	☒	☒
ERS-SAR	http://earth.esa.int/dataproducts/	☒	☒

Table 11. Radar data for high resolution satellite data

2.4.1.3 Medium and low spatial resolution

Data with a resolution of less than 50 meters are conventionally referred to as medium resolution data (moderate resolution, MR), and synthesizer for a few kilometres beneath the low resolution data (low resolution, LR). Due to the reduction of spatial resolution, images can be obtained for a larger area (large field of view of sensors), including a large number of spectral faeces and with high temporal resolution (several dozen times a day). MR and LR data are used to monitor land, atmosphere, and oceans on a small scale. Applications of this type are often scientific endeavours, hence most of the MR and LR data are made available by scientific institutions or space agencies, occasionally by commercial companies.

Sensor	Website	FREE	PAID
Sentinel – 3	http://earth.esa.int/dataproducts/	☒	
AVHRR	http://archive.eumetsat.int/	☒	
	http://www.class.noaa.gov/	☒	
AATSR	http://earth.esa.int/dataproducts/	☒	
AMSR	https://nsidc.org/data/amsre/data_summaries/index.html	☒	
CBRES 1-2/2B/ WFI	http://www.satimagingcorp.com/		☒
CBRES 1-2/2B / IRMSS	http://www.satimagingcorp.com/		☒
Meteosat MVIRI and SEVIRI	http://archive.eumetsat.int/	☒	
	http://www.ssec.wisc.edu/datacenter/archive.html	☒	
MODIS-Cryosphere	http://nsidc.org/data/modis/	☒	
MODIS-Lądy	http://edcdaac.usgs.gov/dataproducts.asp	☒	
MERIS	http://earth.esa.int/dataproducts/	☒	☒
GOES Imager Sounder	http://www.class.noaa.gov/	☒	
	http://www.ssec.wisc.edu/datacenter/archive.html	☒	
IRS-1C/1D WIFS – 180 m	http://www.nrsc.gov.in/		☒
	http://www.euromap.de/		☒

Table 12. Optical data (visible and infrared radiation) Medium and low spatial resolution

Sensor	Website	FREE	PAID
ALOS-PALSAR	http://earth.esa.int/dataproducts/		☒
COSMO-SkyMed	http://www.e-geos.it/		☒
	http://www.cosmo-skymed.it/		☒
RadarSat-2	http://www.radarsat2.info/		☒
	http://gs.mdacorporation.com/		☒
	http://www.geosystems.pl/		☒
ENVISAT-ASAR	http://earth.esa.int/dataproducts/	☒	☒

Table 13. Radar data for Medium and low spatial resolution

2.4.1.4 Digital terrain models

Digital terrain models (Digital Elevation Models, DEMs) are a valuable supplement to image data . Some of the satellites/sensors mentioned above allow the creation of this type of data. DEM as a product is then published/sold on a par with satellite images, most often it also covers the same area as a typical scene. However, there are also global models - covering the entire world with DEM mosaics from multiple passes of a given sensor. The most popular (e.g. thanks to free access to them) are SRTM and ASTER-GDEM:

Sensor	Website	FREE	PAID
SRTM (90m)	http://srtm.csi.cgiar.org/	☒	
ASTER-GDEM (30m)	http://www.gdem.aster.ersdac.or.jp/	☒	
	https://wist.echo.nasa.gov/	☒	

Table 14. Digital terrain models

2.4.2 Open-source vs commercial software

In previous sections, we have analysed the definition of open source, the most widely used licences in open-source software, as well as an analysis of the pros and cons of using open source software in the case of GIS. Due to their similarity to the case of software used for processing remote sensing data, no further analysis will be carried out, as the conclusions obtained in the comparisons done in previous sections for the case of GIS can be extrapolated for the case of remote sensing tools. Therefore, this report will focus on the main characteristics offered by proprietary and open-source software in the processing of remote sensing data.

The main open-source software used in the processing of remote sensing data are described below (Table 15).

Package [Developer]	Description
The Sentinel Toolbox [European Space Agency]	This package offers a repertoire of tools to perform satellite image analysis from Sentinel fleet data and analyse aspects such as multispectral images, radar data, polarimetry or elaborate interferograms.
QGIS Semi-Automatic Classification Plugin [QGIS Development Team]	This QGIS plugins allows to preview and download Sentinel, Landsat, ASTER and MODIS images without having to access the usual portals, and being able to download all the original satellite bands at maximum resolution.
SAGA GIS [Department for Physical Geography, Göttingen, Germany]	SAGA GIS has a rich library grid, imagery, and terrain processing modules. As well as a basic supervised classification tool.
ORFEO Toolbox [Centre national d'études spatiales]	ORFEO is an open-source project which can process high resolution optical, multispectral and radar images, having a wide variety of applications: ortho-rectification, pansharpening, classification, SAR processing, …
GRASS [GRASS Development Team]	Grass allows, among others: image classification, principal components analysis, edge detection and radiometric corrections.
PolSARPro [European Space Agency]	The Polarimetric SAR Data Processing and Educational Tool can handle dual and full polarization SAR of different satellites equipped with radar sensors. This package contains different tools like radar decompositions, inSAR processing or calibration.
Whitebox GAT [John Lindsay]	Whitebox GAT is a platform for advanced geospatial data analysis. Whitebox stands out for its LiDAR tools being a swiss-army knife for this kind of data.

Package [Developer]	Description
gvSIG [gvSIG Association]	gvSIG allows the user to perform supervised classification, band algebra or decision trees of remote sensing data.
Opticks [Ball Aerospace & Technologies Corp.]	Opticks package contains plugins for raster math, treatment of hyperspectral and multispectral data, and radar.
InterImage [Pontifical Catholic University of Rio de Janeiro (PUC-Rio) and the Brazilian National Institute for Space Research (INPE)]	InterImage specialized in automatic image interpretation. The main characteristic is object-based image analysis which explore spectral, geometric, and spatial properties to perform segmentations and classifications of objects.
ILWIS [52°North ILWIS Community]	ILWIS has different features as the possibility to work with anaglyph, stereoscopy and photogrammetry tools. One of the most remarkable is its image classification tool.
E-foto [Rio de Janeiro State University's School of Engineering]	This software provides a set of functional photogrammetry tools, some of the main functionalities are the possibility of performing phototriangulation, stereoscopic modelling and extraction of digital elevation models.
OSSIM [Several US government agencies]	OSSIM is one of the most compatible remote sensing packages, supporting more than 100 raster and vector formats, and at least 4000 types of projections

Table 15. Open source remote sensing packages. Source: GISGeography.com (2020) and personal compilation.

On the other hand, it is also interesting to know the most used proprietary software in the processing of remote sensing data. The main proprietary packages used in the processing of remote sensing data are described in the next table (Table 16).

Package [Developer]	Description
PCI Geomatica [PCI Geomatics]	The Geomatica's main feature is its data processing performance, allowing users to use satellite and aerial images for advanced analysis. Geomatica has been used by many educational institutions and scientific programs around the world to analyse satellite images and trends.
ERDAS IMAGINE [Hexagon Geospatial]	ERDAS IMAGINE is primarily designed for processing geospatial raster data and allows the user to prepare, display and enhance digital images for use in GIS or CAD software. It contains a toolbox that allows the user to perform many operations on an image.

Package [Developer]	Description
ENVI [Harris Geospatial]	ENVI is one of the most widely used packages in the field of remote sensing. It groups together several scientific algorithms for image processing, many of which are automated through a wizard-based approach that guides users to perform complex tasks.
Google Earth [Alphabet Inc.]	Google Earth is the most widely used remote-sensing software in the world. This computer program shows a 3D representation of the Earth based mainly on satellite images. The program maps the Earth by overlaying satellite images, aerial photographs, and GIS data on a three-dimensional globe, allowing users to view cities and landscapes from various angles.
TerrSet [Clark University]	TerrSet (formerly IDRISI) is a package that provides tools for researchers and scientists engaged in the analysis of the dynamics of the Earth system. This software is distinguished by its support to the user in decision making, responsible environmental management, sustainable resource development and equitable resource allocation.
eCognition [Trimble Inc.]	The eCognition package consists of three components that can be used independently or in combination to solve image analysis tasks. eCognition Developer is a development environment for object-based image analysis, used in the earth sciences to develop rule sets for remote sensing data analysis. eCognition Architect allows users to configure, calibrate and run image analysis workflows created in eCognition Developer. eCognition Server provides a processing environment for batch execution of image analysis tasks.
ArcGIS [Esri]	ArcGIS is a software package formatted by ArcGlobe and ArcScene (regional 3D visualization), ArcEarth (global 3D visualization) and ArcMap, used for cartographic production, analysis, and visualization. The main potential of ArcGIS is its extensions, which allow any cartographic task to be carried out quickly and efficiently.

Table 16. Proprietary remote sensing packages. Source: Personal compilation.

Recently new types of satellite data processing solutions have emerged. They are online platforms and virtual laboratories, which provide software, data, and computational capabilities via internet. Some of them are free (e.g. openEO platform), other operate as commercial solutions (e.g. Data and Information Access Services – DIAS). The biggest advantages of such platforms are that users do not have to buy separately, data, software and hardware. Instead, they can obtain temporal access to all these facilities.

DIAS (Data and Information Access Services) platforms offer some of functionality for free, and more advanced functionality on commercial basis. The prize depends on the

number of virtual machines, data amount for processing, time of usage. There are five different platforms: ONDA, sobloo, CREODIAS, mundi and wekeEO. All of them contain comprehensive information of products and various Copernicus services. Due to technological evolution, the European Copernicus programme has become the largest space data provider in the world producing 12 terabytes per day. The European Commission has funded the deployment of five cloud-based platforms to facilitate and standardise access to data. They provide centralised access to Copernicus data and information, as well as to the processing tools.

The openEO platform, provided by ESA, allows to analyse the data with programming language such as R, Python and JavaScript. It provides plenty of data available from different satellites such as Sentinel 1 GRD, Sentinel 2 L2A, Sentinel 3 SLSTR, 5P Landsat 8 L2 and MODIS inclusive of some derived products. It offers a free trial for 30 days for those who want to get insight of the program, and for those who know how to use the openEO platform, they can register as Early Adopter which is also freely available for 90 days.

Figure 5. the overview of the openEO platform. Source: https://openeo.cloud/

The Copernicus program is a European Earth Observation and monitoring programme. It is developed in partnership with the Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites

(EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF),
EU Agencies and Mercator Océan.

3. SUCCESS STORIES FOR REMOTE SENSING TECHNIQUES

For objective identification, monitoring, management, and future utilization of
underutilized lands at a regional or global scale, remote sensing and modern
interpretation techniques are being widely used (Nalepa y Bauer, 2012). In order to know
in depth how remote sensing is being used in marginal lands, it is necessary to carry out
a literature review of the studies and projects that have targeted marginal lands, and how
they have used remote sensing to reach their objectives.

This literature review has focused on three different topics, focusing on the objective of
this project:

- Forests, carbon sequestration and remote sensing.
- Satellite identification and monitoring of marginal lands.
- Carbon-Based management on marginal lands.

3.1 Forests, carbon sequestration and remote sensing

The first part of this list of success stories in the use of remote sensing on marginal lands has focused on the use of remote sensing in forests and carbon sequestration. This project aims at land use change on marginal lands for the creation of carbon sinks, i.e. the creation of forests.

For decades, remote sensing has been used to quantify biomass (Brown, 1996), from its use in forestry projects (Brown, 1996) to agriculture (Watts et al., 2009).

Author	Title	Remote sensor / mission
(Pereira y Navarro, 2015)	Rewilding European Landscapes	-
(Wilson y Gerard, 2007)	Carbon capture and sequestration: integrating technology, monitoring, regulation	-
(Turner et al., 2004)	Monitoring forest carbon sequestration with remote sensing and carbon cycle modelling	Landsat-7 ETM+
(Watts et al., 2009)	Monitoring of cropland practices for carbon sequestration purposes in north central Montana by Landsat remote sensing	Landsat-7 ETM+
(Brown, 1996)	The utility of remote sensing technology in monitoring carbon sequestration agroforestry projects	AVHRR, Landsat (MSS and TM), SPOT, AVIRIS, CASI, RADARSAT, LEWIS and CLARK
(Kale et al., 2009)	Patterns of carbon sequestration in forests of Western Ghats and study of applicability of remote sensing in generating carbon credits through afforestation/reforestation	Landsat-5 TM, IRS
(González-Alonso et al., 2006)	Forest biomass estimation through NDVI composites. The role of remotely sensed data to assess Spanish forests as carbon sinks	

Author	Title	Remote sensor / mission
(Patenaude et al., 2005)	Synthesis of remote sensing approaches for forest carbon estimation: reporting to the Kyoto Protocol	...

Table 17. Forests, carbon sequestration and remote sensing review. Source: Personal compilation

3.2   Satellite monitoring of marginal lands

The literature review carried out on the monitoring of marginal lands by using remote sensing shows that its study has traditionally been carried out with a final vision focused on the objective to be achieved. For this reason, the review shown below contains projects as diverse as the monitoring of marginal lands in armed conflicts in order to understand the migratory movement or the risk of abandonment of crops in the framework of the common agrarian policy.

Author	Title	Remote sensor / mission
(Witmer y O'Loughlin, 2009)	Satellite Data Methods and Application in the Evaluation of War Outcomes: Abandoned Agricultural Land in Bosnia-Herzegovina After the 1992–1995 Conflict	Landsat-5 TM, Quickbird
(Löw et al., 2015)	Mapping abandoned agricultural land in Kyzyl-Orda, Kazakhstan using satellite remote sensing	Landsat-5 TM, Landsat-8 OLI, RapidEye
(Ruskule et al., 2012)	Patterns of afforestation on abandoned agriculture land in Latvia	Colour orthophoto maps
(Liu et al., 2015)	Monitoring vegetation recovery at abandoned land	Landsat-7 ETM+, SPOT5
(Milenov et al., 2014)	Monitoring of the risk of farmland abandonment as an efficient tool to assess the environmental and socio-economic impact of the Common Agriculture Policy	SPOT4, SPOT5, AVHRR

Author	Title	Remote sensor / mission
(Ray et al., 1993)	Monitoring land use and degradation using satellite and airborne data	Landsat-5 TM, Landsat 8
(Proisy et al., 2018)	Monitoring mangrove forests after aquaculture abandonment using time series of very high spatial resolution satellite images: A case study from the Perancak estuary, Bali, Indonesia	Geoeye, Quickbird, Worldview-2 and Worldview-3, Ikonos
(Steininger, 2000)	Satellite estimation of tropical secondary forest above-ground biomass: data from Brazil and Bolivia	Landsat-5 TM
(Drummond y Loveland, 2010)	Land-use pressure and a transition to forest-cover loss in the eastern United States	Landsat-5 TM, Landsat-5 MSS, Landsat-7 ETM+
(Schepaschenko et al., 2015)	Estimation of forest area and its dynamics in Russia based on synthesis of remote sensing products	SPOT4, ENVISAT-MERIS, MODIS, ALOS PALSAR, ENVISAT ASAR
(Brink y Eva, 2009)	Monitoring 25 years of land cover change dynamics in Africa: A sample based remote sensing approach	Landsat-5 MSS, Landsat-7 ETM+
(Yusoff et al., 2017)	Towards the use of remote-sensing data for monitoring of abandoned oil palm lands in Malaysia: A semi-automatic approach	SPOT-6
(Ahamed et al., 2011)	A review of remote sensing methods for biomass feedstock production	Landsat-5 TM, Landsat-5 MSS, Landsat-7 ETM+, GOES, AVHRR, ATLAS, SPOT1, SPOT2, SPOT3, SPOT4, LISS-III, LISS-IV, ASTER, MISR, Quickbird, IKONOS, AVIRIS, MODIS, ortophotos
(Tomáš Goga et al., 2019)	A Review of the Application of Remote Sensing Data for Abandoned Agricultural Land Identification with Focus on Central and Eastern Europe	Landsat 7 and 8, MODIS

Author	Title	Remote sensor / mission
(Tobias Kuemmerle et al., 2008)	Cross-border Comparison of Postsocialist Farmland Abandonment in the Carpathians	Landsat 5 TM and Landsat 7 ETM+
(He Yin et al., 2018)	Mapping agricultural land abandonment from spatial and temporal segmentation of Landsat time series	Landsat
(Camilo Alcantara et al., 2013)	Mapping the extent of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data	MODIS
(Andrey Dara et al., 2018)	Mapping the timing of cropland abandonment and recultivation in northern Kazakhstan using annual Landsat time series	Landsat 5 TM, Landsat 7 ETM and Landsat 8 OLI

Table 18. Satellite monitoring of marginal lands review. Source: Personal compilation.

3.3 Carbon-Based management on marginal lands

Finally, the literature review on Carbon-Based Management on marginal lands focuses on the study of carbon sequestration in reforested or afforested areas on marginal lands.

Author	Title	Remote sensor / mission
(Campbell et al., 2008)	The global potential of bioenergy on abandoned agriculture lands	MODIS
(DiRocco et al., 2014)	Accountable accounting: Carbon-based management on marginal lands	-
(Jin et al., 2019)	Management controls the net greenhouse gas outcomes of growing bioenergy feedstocks on marginally productive croplands	-
(Silver et al., 2000)	The potential for carbon sequestration through reforestation of abandoned tropical agricultural and pasture lands	-

Author	Title	Remote sensor / mission
(Potter et al., 2007)	Satellite-derived estimates of potential carbon sequestration through afforestation of agricultural lands in the United States	AVHRR, MODIS
(Montenegro et al., 2009)	The net carbon drawdown of small-scale afforestation from satellite observations	MODIS,
(Bandaru et al., 2013)	Soil Carbon Change and Net Energy Associated with Biofuel Production on Marginal Lands: A Regional Modeling Perspective	Landsat-5
(Urmas Peterson et al., 2008)	Changes in agricultural land use in Estonia in the 1990s detected with multitemporal Landsat MSS imagery	Landsat MSS

Table 19. Carbon-Based management on marginal lands review. Source: Personal compilation.

4. SUCCESS STORIES – REVIEW OF ONGOING PROJECTS

Several projects focused on the topic of carbon sequestration and marginal lands are now ongoing or have been completed. They have been analysed and summarized in this chapter. Each table provides the main information, including objectives, methodology and the results (if such information was available). Different colour coding has been assigned based on type of project. Peach colour indicates an approach similar to the *MAIL* project approach, whereas green colour indicates projects which have used remote sensing or GIS technology. Turquoise colour indicates projects with self-developed models or any other approaches but not remote sensing or GIS technique.

Title	BIOPLAT-EU. Promoting sustainable use of underutilized lands for bioenergy production through a web-based platform for Europe		
Grant agreement	818083	*Duration*	1/11/2018 - 31/10/2021
Project Leader	WIP Renewable Energies (Germany)		
Website	https://bioplat.eu/		
Keywords	Bioenergy, satellite data		

Objective

- To promote the market uptake of sustainable bioenergy in Europe using marginal, underutilized, and contaminated lands for non-food biomass production through the provision of a web-based platform that serves as decision support tool.

Methodology

- Database of maps of MUC in Europe was generated based on high resolution data (Copernicus high resolution layers (HRLs), time series data from Sentinels and other satellites) and their attributes.
- The TABL (Target Area Base Layer) is composed through the blending of images and shapefiles from the Corine Land Cover library and purpose-built time series based on Landsat and Sentinel Images to define the underutilization status of the land in Europe, EUROSTAT demographic and social datasets.
- The STEN (Sustainability Tool for Europe and Neighbouring Countries) tools stems from the Global Bioenergy Partnership Sustainability Indicators for Bioenergy.

Results
• The database is compilation of valuable maps, tools and information addressing sustainable bioenergy production on MUC lands and data compiled by the consortium from governments, public and private partners throughout the project to complete the gaps. • All generated data was included in GIS software with INSPIRE-compliant metadata files attached and transferred to a dedicated online platform.
Online Platforms
• **Twitter, Facebook and Instagram:** BioplatEU & **Youtube:** Project BIOPLAT-EU • **Newsletter** subscription from website.

Table 20. Summary of information about BIOPLAT-EU project.

Title	GRASSMARGINS Enhancing biomass production from marginal lands with perennial grasses		
Grant agreement	289461	**Duration**	1/10/2011 – 30/09/2015
Project Leader	TEAGASC - Agriculture And Food Development Authority(Ireland)		
Website	https://cordis.europa.eu/project/id/289461		
Keywords	GrassPortal, perennial grass, DIVA-GIS		
Objective			
• To identify, categorize and develop novel varieties of C3 grasses (Dactylis glomerata, Festuca arundinacea and Phalaris arundinacea) and the C4 genus Miscanthus, which can be grown on marginal lands with less input.			
Methodology (EO)			
• To identify the species, 29 genotype were selected from the geno pools and specific tests were performed under controlled conditions in lysimeter, greenhouse and climatic condition chamber. The tolerance to salt, drought, flooding, cold and frost were analysed for grass species with different methodologies. • The data was gathered using the '**GrassPortal**' database, which combines information from Floras, herbaria searches and national biodiversity			

databases. It also has global climate data due to global climatology reconstructed for the CRU CL 2.0 dataset (http://www.cru.uea.ac.uk).

- They employed high-resolution mapping and climatic envelope modelling (CEM) to identify places in Europe that are best suited for the cultivation of each bioenergy crop, including marginal habitats.

- • The CEMs were calculated using BIOCLIM and then implemented in DIVA-GIS. Advanced algorithms like the Genetic Algorithm for Rule-set Production (GARP) and Maxent were also tested.

- Generalized Linear Models, Random Forests, Generalized Boosting Models, Artificial Neural Networks, Classification Tree Analysis, Multiple Adaptive Regression Splines, Flexible Discriminant Analysis, and Generalized Additive Models, Maxent, and Surface Range Envelope. **Species distribution models** (SDM) have been built for each of the species, predicting with their distributions and identifying the suitable climate conditions required by each species.

Results

- Grass yields obtained from marginal lands are not less than yields from good agricultural lands.

- Marginal lands can be stimulated by adding high amount of nitrogen content and optimized nitrogen leaching. Sandy soils, nitrate leaching will be reduced approx. by 50 kg N/ha when annual crops are substituted by perennial crops even when they are fertilized.

Online platforms

- Organized several **workshops** to create awareness about environment and sustainability. An inter project meeting and public event in Dublin on June 24-26, 2014 and provided information about EU and non EU research projects working on perennial grasses.

- **Twitter and facebook id**: 'Grassmargins'.

- **Google Playstore**: Grassmargins Portal, for collecting grass data.

- An application developed named '**PANACEA**' and it also has registration availability for newsletter of this project.

Table 21. Summary of information about GRASSMARGINS

Title	MAGIC: Marginal lands for Growing Industrial Crops: Turning a burden into an opportunity		
Grant agreement	727698	Duration	1/7/2017 – 30/6/2021
Project Leader	Center For Renewable Energy Sources And Savings Foundation (Greece)		
Website	https://magic-h2020.eu/		
Keywords	Magic crops, magic maps, DSS, Quickscan		

Objective

- This is a 4 years project which aims at promoting sustainable development of the resource efficient and economically profitable industrial crop cultivation in Marginal Lands.

Methodology (EO)

- MAGIC is an up to date database which consist of two data sets: MAGIC CROPS and MAGIC MAPS into a Decision Support System.

- In **MAGIC CROPS**, industrial crops are categorized based on its agronomic characteristics such as yield performance, input requirements and quality traits for end user applicants. **MAGIC MAPS** analysis the marginal lands in Europe. This mapping is based on the previous classifications according to factors such as biophysical, socio economic, sustainability. Moreover, **DSS** gives information about most productive industrial crop based on the geological requirements of the soil to the farmers.

- MAGIC's spatial explicit categorization is used to establish sustainable best-practice alternatives for industrial crops across Europe by using QUICKScan method.

- Furthermore, the spatially explicit map database is accessible via the project website and will be maintained and developed for the duration of the project, as well as for at least five years after it is completed.

Results

- According to this study, marginal lands account for 29% of agricultural land in the European Union (as classified by CLC since 1992).

- Adverse rooting conditions, adverse climatic circumstances, and unfavorable terrain are the main reasons for the increase in marginal lands.

• Growing industrial crops on marginal lands can help to alleviate land use competition for food production, which has negative consequences for food security, land-based greenhouse gas emissions, and biodiversity loss .	
Online Platforms • For further information, register to **EIP-AGRI website**. • Organizes several **workshops** and other events to advice farmers and it also provides opportunity to share our own research practice through the online '**Share**' section.	

Table 22. Summary of information about MAGIC project

Title	FORBIO Fostering sustainable feedstock production for advanced biofuels on under utilised land in Europe		
Grant agreement	691846	*Duration*	01/01/2016 - 31/12/2018
Project Leader	WIP Renewable Energies & GEONARDO		
Website	https://forbio-project.eu/		
Keywords	Bioenergy, sustainability		
Objective • Identification of social, economic, environmental and governance-related opportunities and challenges for advanced bioenergy deployment through a series of multi-stakeholder consultations. • Evaluation of the agronomic and **techno-economic potential** of the selected advanced bioenergy value chains in the case study sites of the target countries. • Assessment of the environmental, social and economic sustainability of the selected advanced bioenergy value chains in the target countries. • Analysis of the economic and non-economic barriers to the market uptake of the selected sustainable bioenergy technologies; and development of strategies to remove the aforementioned barriers, including identification of roles and responsibilities of relevant stakeholders • Encourage European farmers to produce non-food bioenergy carriers and capacity building of economic actors and other relevant stakeholders for setting up sustainable bioenergy supply chains.			

Methodology

- In the context of FORBIO project, the approach is to adapt the calculation of sustainability performance of bioenergy planned at local level in Germany, Italy and Ukraine.

- The assessment aims at determining the actual change between the current situation (baseline) and the hypothetical situation (target) in which bioenergy is produced.

- The differences between this two time periods are evaluated automatically by an assessment tool called 'FORBIO Assessment Tool of Sustainability **(FAST)**' to establish their performances under the selected sustainability indicators developed by Global Bioenergy Partnership (GEPB) and checked against EU regulations and directions.

Results

- Roadmap to remove barrier of the main economic and non economic barriers to the market uptake of advanced bioenergy.

- Has developed a methodology to assess the sustainable bioenergy production potential on available "underutilized lands" in Europe (contaminated, abandoned, marginal, fallow land etc.) at local, site-specific level.

Online Platforms

- **Twitter:** FORBIO_H2020

- **Youtube:** Project BIOPLAT-EU

- Organizes several **workshops** and events for farmers, land owners and stockholders.

Table 23. Summary of information about FORBIO project

Title	SEEMLA Sustainable exploitation of biomass for bioenergy from marginal lands in Europe		
Grant agreement	691874	*Duration*	1/01/2016 - 31/12/2019
Project Leader	Fachagentur Nachwachsende Rohstoffe Ev (Germany)		
Website	https://www.seemla.eu/home/		
Keywords	Bioenergy, SQR tool, spatial datasets, Biofuel		

Objective

- To promote re-conversion of ML for the production of bioenergy through the direct involvement of farmers and forester.

- To strengthen local small-scale supply chains.

- To promote plantations of bioenergy plants on MLs

Methodology (EO)

- The development of the common methodology depends on the indicators derived in Task 2.3 in the project.

- The coverage of the spatial datasets is either global or European and they mainly come from the European Soil Data Centre - ESDAC (Panagos et al., 2012), Food and Agriculture Organization of the United Nations (FAO) and the WorldClim – Global Climate Data.

- They had evaluated the degree of marginality using the Muencheberg soil quality rating (SQR tool), a GIS tool, to assess soil fertility as a key factor in determining marginality.

- The algorithm comprises four phases:

  i. identification of marginal lands using the SQR index

  ii. exclusion of MagLs unsuitable for biomass production for bioenergy

  iii. selection of suitable bioenergy crops

  iv. rating of marginal lands.

Results

- It implemented a sustainable land-use strategy for a sustainable production of plant-based energy on marginal lands.

- The "SEEMLA approach" was developed as an integrated set of environmental, ecological, social, economic, and biophysical criteria, in order to re-convert degraded and marginal lands in the name of the production of bioenergy.

- The results of the ending SEEMLA project were shared with a broad group of stakeholders (scientists, farmers, foresters, policy decision makers, etc.)

Online Platforms

- It had organized **workshops and events** on future biofuels.

- **Twitter and Facebook** id: SEEMLA

- **Newsletter** registration can be done from website.

Table 24. Summary of information about SEEMLA project

Title	GRACE GRowing Advanced industrial Crops on marginal lands for biorEfineries		
Grant agreement	745012	Duration	1/06/2017 - 31/05/2022
Project Leader	Universitaet Hohenheim (Germany)		
Website	https://www.grace-bbi.eu/		
Keywords	Miscanthus, crop production		
Objective			

Objective

- Upscaling of miscanthus crop production

- Production of both miscanthus and hemp on lands of low productivity, abandoned land or land with contaminated soil

- Establishment of 10 biobased value chains at a scale of relevance to industry.

Online Platforms

- **Twitter** and **Facebook**: GRACE-BBI

Table 25. Summary of information about GRACE project

Title	Energy crops on marginal lands in the mediterranean area of the community (Biomassa Perugia).		
Grant agreement	EN3B0046	Duration	1/05/1986 - 30/06/1989
Project Leader	Azienda Agricola Baldelli Celozzi		
Website	https://cordis.europa.eu/project/id/EN3B0046		
Objective			

Objective

- To optimize the productivity of fast growing forestry on Marginal Lands.

Table 26. Summary of information about Energy crops on marginal lands in the Mediterranean area of the community

Title	Land use systems in the Mediterranean mountains and marginal lands		
Grant agreement	AIR32426	Duration	1/01/1995 - 31/12/1999
Project Leader	International Centre For Alpine Environments		
Website	https://cordis.europa.eu/project/id/AIR32426/de		
Objective			

- To examine the influence of subsidies generated from EC policies on livestock grazing practices in Mediterranean mountainous and marginal areas, and to create optimal grazing techniques for a rational management of natural resources compatible with economic and environmental aspects..

Table 27. Summary of information about Land use systems in the Mediterranean mountains and marginal lands

Title	Adaptation and selection of Mediterranean pinus and cedrus for sustainable afforestation of marginal lands		
Grant agreement	FAIR950097	Duration	1/03/1996 - 28/02/2000
Project Leader	I.N.R.A.		
Website	https://cordis.europa.eu/project/id/FAIR950097		

Table 28. Summary of information about Adaptation and selection of Mediterranean pinus and

Title	LIBBIO Lupinus mutabilis for Increased Biomass from marginal lands and value for BIOrefineries		
Grant agreement	720726	Duration	1/10/2016 - 30/09/2020
Project Leader	Nyskopunarmidstod Islands (Iceland)		
Website	http://www.libbio.net/		
Keywords	Bio energy, modern crop breeding technology		
Objective			
	- Using bio-refinery cascading principles for crop value generation and modern crop breeding technology, produce consumer food, feed, non-food, and bio-energy products from Andean lupin varieties (Lupinus mutabilis) adapted to European farming circumstances. - Using state-of-the-art solvent-free technology for raw material processing, boost crop yield and harvest index, and speed supply chain growth through a consumer-driven strategy to generating high-value-added food and non-food items.		
Online Platforms			
Youtube: Iceland Innovation Centre			

Table 29. Summary of information about LIBBIO project

Title	CIRCASA Coordination of International Research Cooperation on soil CArbon Sequestration in Agriculture		
Grant agreement	774378	*Duration*	1/11/2017 - 31/10/2020
Project Leader	Institut National De La Recherche Agronomique (France)		
Website	https://www.circasa-project.eu/		
Keywords	Sequestration, food security		

Objective

- Improve our understanding of agricultural soil carbon sequestration and its potential for climate change mitigation and adaptation, as well as for increasing food production.

- Co-design a strategic research agenda on soil carbon sequestration in agriculture with stakeholders.

- Strengthen the international research community on soil carbon sequestration in relation to climate change and food security.

Online Platforms

- **Twitter:** CIRCASAproject

- **Newsletter** subscription from website.

- Has organized several **events** and **webinars**

Table 30. Summary of informartion about CIRCASA project

Title	EUROCHAR Biochar for Carbon sequestration and large-scale removal of greenhouse gases (GHG) from the atmosphere		
Grant agreement	265179	*Duration*	1/01/2011 - 30/03/2014
Project Leader	Consiglio Nazionale Delle Ricerche (Italy)		
Website	https://cordis.europa.eu/project/id/265179		
Keywords	Biochar, carbon sequestration		

Objective

- EuroChar investigated carbon sequestration potentials that can be achieved by transforming plant biomass into charcoal (or Biochar) and add that to agricultural soils at European scale.

Table 31. Summary of infromation about EUROCHAR project

Title	Carbon storage in European grasslands		
Grant agreement	627	Duration	10/05/2000 - 9/05/2005
Project Leader	N/A		
Website	https://cordis.europa.eu/project/id/627		
Objective			

- To quantify, carbon storage in European grassland ecosystems through experimentation and modelling, and to identify the mechanisms controlling carbon allocation in plants and soils of grasslands.

Table 32. Summary of information about Carbon storage in European grasslands

Title	CASFOR-II Casfor-ii: modelling carbon sequestration in forested landscapes		
Grant agreement	ICA4-CT-2001-10100	Duration	1/12/2001 - 30/11/2004
Project Leader	Wageningen University (Netherlands)		
Website	http://dataservices.efi.int/casfor/		
Keywords	Carbon balance		
Objective			

- Create a general model for calculating carbon balance and sequestration capacity in wooded landscapes or regions.
- Using the Internet, propagate the developed **CO2FIX model** to the user community.

Table 33. Summary of information about CASFOR-II project

Title	SusCrop- ERA-NET Cofund on Sustainable Crop Production		
Grant agreement	771134	Duration	NA
Project Leader	Project Management Jülich, Forschungszentrum Jülich GmbH		
Website	https://www.suscrop.eu/		
Keywords	Sustainable Crop Production		
Objective			

- To strengthen the European Research Area (ERA) in the field of sustainable crop production by enhancing collaboration and coordination across national and regional research programs.

Online Platforms

- **Instagram** & **Twitter:** SusCrop- ERA-NET
- **Newsletter** subscription from website.

Table 34. Summary of information about Sus Crop- ERA-NET Cofund on Sustainable Crop Production

Title	OPTIMISC (Optimizing Miscanthus Biomass Production - OPTIMISC)		
Grant agreement	289159	*Duration*	01/10/2011 - 31/03/ 2016
Project Leader	University of Hohenheim		
Website	https://cordis.europa.eu/project/id/289159/reporting/de		
Keywords	Miscanthus, bioenergy		

Objective

- To improve the miscanthus bioenergy and bioproduct chain by:
    - a) testing elite germplasm types in a variety of locations across Europe, Ukraine, and Russia.
    - b) Analyzing key traits that currently limit the potential of miscanthus.
    - c) identifying high-value bioproducts.
    - d) Modelling the combined results to provide recommendations to policymakers, growers, and industry.

Table 35. Summary of information about OPTIMISC project

Title	4F CROPS (Future Crops for Food, Feed, Fiber and Fuel)		
Grant agreement	212811	*Duration*	01/06/2008 - 30/11/2010
Project Leader	Centre for Renewable Energy Sources and savings foundation, Greece		
Website	https://cordis.europa.eu/project/id/212811/reporting		
Keywords	Biofuels, GIS, spatial		

Objective

- Potential impact to prove a competitive bio economy through the production of both biofuels and biobased products could be a viable option for Europe.

Methodology
• The analysis of land availability was based on **spatial** agro-climate data and performed in GIS software.   • A major assumption would be that food production cannot be affected, else the food market risks to be distort, and thus the non-food crops can be cultivated only on a surplus land.   • **Databases** like Corine Land Cover, Soil Geographical Database, etc will be used in order to identify the terrain conditions.
Results
• European maps indicating possible development on non-food cropping systems
Online Platforms
• Has organized 5 **workshops** and **events.**

Table 36. Summary of information about 4F CROPS project

Title	MISCOMAR project - Horizon 2020		
Grant agreement	N/A	*Duration*	01/03/2020 - 28/02/2022
Project Leader	Aberystwyth University, Institute of Biological, Environmental and Rural Sciences		
Website	https://www.miscomar.eu/		
Keywords	Miscanthus		
Objective	• MISCOMAR+ will use interdisciplinary academic and industrial expertise to expand the evidence basis for **Miscanthus** as a leading perennial bioenergy crop for Marginal, Contaminated, and Industrially Damaged Land (MaCL), including innovative Miscanthus hybrids designed for climate change resilience.		
Results	• Improved establishment methods for increased resilience under climate change and challenging soil conditions • Identification and demonstration of economic utilization options for miscanthus biomass from MaCL • Identification of environmental sustainability indicators under long-term miscanthus cultivation.		

> *Online Platforms*
> - **Twitter**, **Facebook** and **LinkedIn**: Miscomar Project+

Table 37. Summary of information about MISCOMAR project

5. GUIDELINES FOR THE USE OF MARGINAL LAND AS A CARBON SINK

5.1 European Framework: Forest and adaptation to climate change

Forests and other woodlands are essential for human health and wellbeing, as they are important habitats rich in biodiversity, provide primary materials for the paper, cork and furniture industries, revitalize the rural environment creating employment and tourism, regulate the air we breathe, clean the water we drink and are the key to combating climate change and enhancing the health of the planet (European Commission, 2021a). According to the Draft of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) decision proposed by the President at COP26, actions to protect and restore forests are critical to mitigate climate change by reducing CO2 emissions, increasing CO2 sequestration and protecting biodiversity (COP26, 2021). Despite this human need for forests, climate change continues to negatively affect forests, particularly, but not only, in areas with monospecific and even-aged stands(European Commission, 2021a). Climate change has also highlighted the vulnerability of forests to other pressures such as pests, pollution and disease, and affects forest fire regimes, leading to conditions in which the extent and intensity of forest fires in the EU will increase in the next few years (Costa *et al.*, 2020).

Therefore, the new European Union forest strategy for 2030 consists of improving monitoring to better assess the state of our forests, reversing negative trends, duplicating our efforts to protect and restore forest biodiversity to ensure the resilience of forests, increasing forest cover (European Commission, 2021a), and can respond to a climate that is changing and will continue to change with devastating effects even if we reduce emissions (COP26, no date). The strategy also includes ensuring the long-term availability of wood for use in construction beyond what is currently used, as well as boosting non-timber forest-based economic activities to promote the diversification of local economies and employment in rural areas. With this Strategy, the Commission aims to make the transition to a modern, climate neutral and resource-efficient economy

(European Commission, 2021a). For this transition to climate neutrality to be successful, we need our existing forests to be larger, more diverse and healthier, increasing carbon capture and storage, halting species and habitat loss, and reducing the effects of air pollution on human health. This target is aligned with **the commitment to plant 3 billion trees by 2030** in the framework of the European Green Deal, whose success is expected to be achieved by restoring damaged ecosystems through reforestation or creating new forests through sustainable and ecologically balanced afforestation while taking due consideration of environmental, economic and social values with a view to mitigating the possible negative effects of large-scale afforestation (European Commission, 2021b). In this context, marginal lands are (mostly) degraded and fragile areas, with a reduced capacity to cope with extreme events and to contribute to carbon sequestration targets. For this reason, the rehabilitation of marginal lands with the intention of creating new forests that contribute to carbon sequestration represents a unique opportunity to comply with the guidelines of the European Green Deal.

The second objective of this deliverable is to provide guidelines for the future exploitation and management of marginal lands by any relevant actor in Europe, focused on the use of marginal lands as carbon sinks through afforestation and reforestation projects.

5.2 Marginal lands under carbon sequestration management and other positive externalities

Given the deficient management by public and private administration of marginal lands, we can consider marginal lands as both a problem and an opportunity. They are an important problem from an environmental or socioeconomic point of view, as they contribute to the reduction of biodiversity, increase the risk of fires, promote soil loss and reduce economic opportunities in rural areas, among others. But, on the other hand, they are an opportunity to increase forest cover, restore degraded forests and expand the European Union's natural carbon sinks between now and 2030.

There is no common agreement on the concept of marginal lands, and in general, the definition has changed as a result of the circumstantial dynamics of the MLs themselves, which put these land areas in a state of resource transition, very sensitive to natural processes, economic impacts and diverse management (Torralba *et al.*, 2021). It is this last, land management, that has given the greatest differences in interpretations of the ML definition, because the definition is associated with the pursuit of land to achieve various management objectives, such as the increase of bioenergy crops (Ciria *et al.*,

2019; Mellor *et al.*, 2021), food-producing land (Zhang *et al.*, 2018) or carbon
sequestration through reforestation (Sauer *et al.*, 2012).

According to the UNFCCC Sustainable Land Management (SLM) report, afforestation
and reforestation are effective systems for preventing land degradation and rehabilitating
degraded land and is an effective climate change mitigation strategy (Sanz *et al.*, 2017).
In terms of carbon sequestration, reforestation and afforestation of tree species fix more
carbon due to the greater accumulation of biomass above and below the ground than
other types of vegetation such as scrub or grasslands (Silver, Ostertag and Lugo, 2000;
Bazrgar *et al.*, 2020). In forest lands that have been harvested or affected by
disturbances that eliminate the forest stand, deliberate reforestation allows a two- to
three-fold increase in C accumulation in aboveground biomass compared to natural
regeneration (Nave *et al.*, 2019). At the same time, reforestations also influence the soil
carbon stock, because although soil C is not particularly sensitive to the type of soil cover,
the establishment of a forest on an area that was cultivated causes an increase in carbon
stocks in the topsoil. (Nave *et al.*, 2019).

On the other hand, given the current and future uncertainty in C dynamics, decisions
driving marginal land-use change to forests can be based not only on carbon
sequestration but also on the suite of ecosystem services that forests provide (DiRocco
et al., 2014). In particular, some of these potential benefits of afforestation and
reforestation when carried out on marginal lands are habitat improvement and
biodiversity enhancement (especially when mixed tree species are used), reduction and
control the soil erosion, preservation of the water cycle and water quality, flood
prevention, reduce desertification, improve ecosystem functions and services, and often
depending on where the new forest areas are located, generate esthetic, recreational
and cultural services, revitalize the rural economy, generate jobs, fix population in rural
areas and generate other non-timber products (resins, mushrooms, cork, fruits such as
pineapples, etc.) that diversify the exploitation and use of forest products.

5.3 Proposal for the use of marginal lands: afforestation and reforestation

Although it depends on each specific case, the land covers where most of the ML have
been attributed are abandoned agricultural lands, grasslands, moorlands, heathlands,
sclerophyllous vegetation and to a lesser extent rocky surfaces (i.e., bare rock, hardpan,
mineral fragments, bare soils and natural deposits) (Georgiadis *et al.*, 2021; Torralba *et*

al., 2021). Since each ML comes from different land use, each ML will require different treatment and considerations prior to reforestation/afforestation (Figure 6).
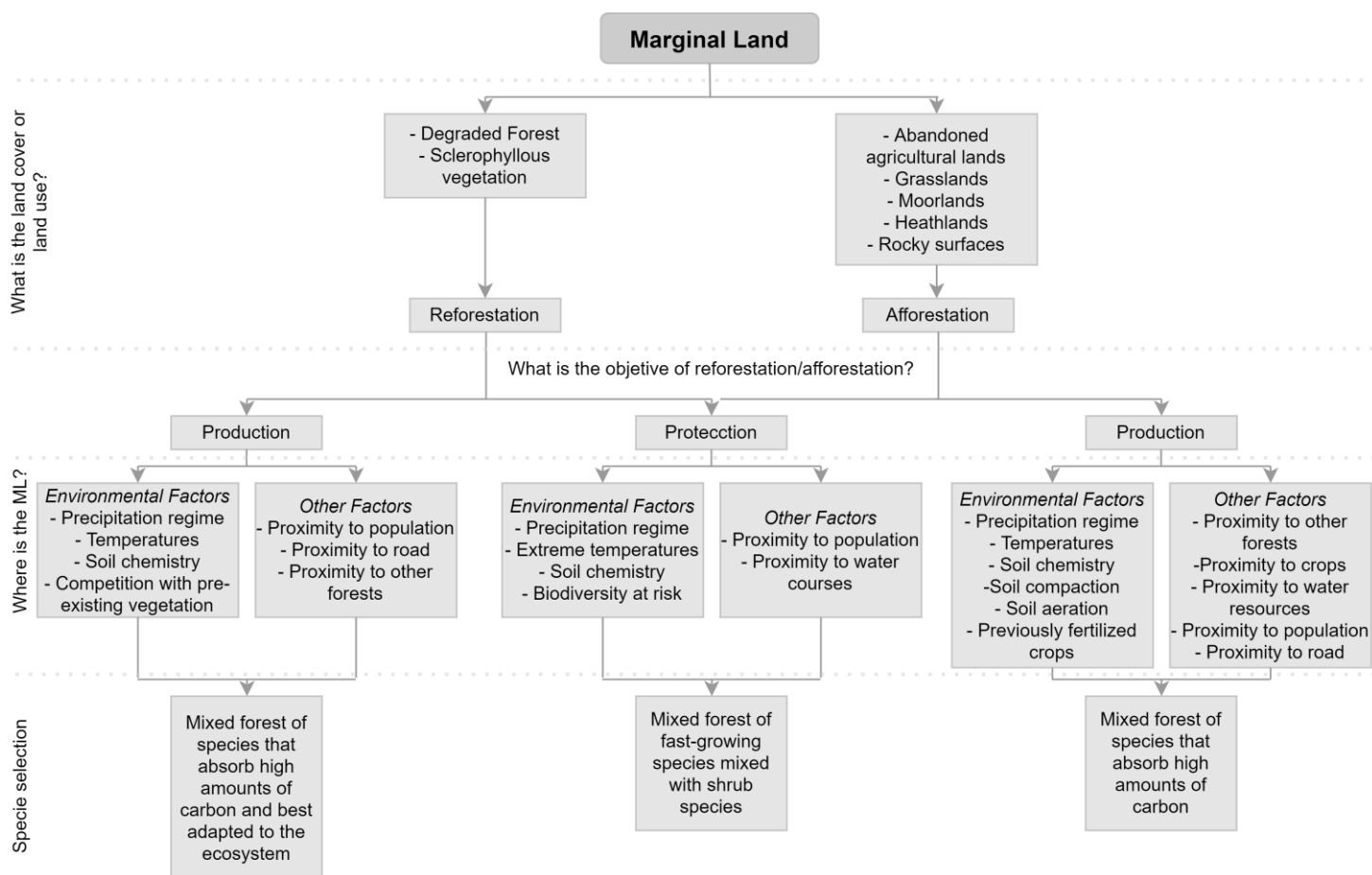

Figure 6. General methodological workflow for reforestation and afforestation in ML. Source: personal compilation of Jesús Torralba Pérez.

Both reforestation and afforestation refer to the human establishment of trees on non-forested land through plantation, seeding and/or human promotion of natural seed sources. According to the IPCC (2000) definition, reforestation refers to the establishment of forests on land that had recent tree cover, i.e., the establishment of trees on land temporarily bare of tree vegetation as a result of harvesting and cutting forestry activities or natural disasters (fires, landslides, floods, etc.). Whereas afforestation refers to lands that have been without forests for much longer, i.e., the planting of new forests on lands that historically have not contained forests, so many definitions refer to this phenomenon as a change in land cover or land use designation.

Given this definition, the reforestation of marginal lands proposed by the **MAIL** project will be carried out on those areas covered by vegetation that by administrative definition (for example, by land use) are forests but have a tree cover of less than 10%, representing a degraded ecosystem that involves soil and biodiversity losses. Also included are those areas that have recently been affected by fire, pests, or any natural disaster that has reduced tree cover and destroyed the vertical and horizontal structure of the forest which has resulted in drastic changes in biodiversity, have a high risk of soil loss and that not optimally contribute to carbon sequestration. On the other hand, for the afforestation of marginal lands, we will consider those areas that do not have forest tree cover and generally refer to other non-forest land uses, so new forests will be planted where there were none.

In addition to considering the objective of fixing carbon with the future forest stand, it is important to consider the preferred reforestation objective of each stand or afforestation, since this objective will determine the following silvicultural actions. Consequently, reforestation or afforestation can have both protective and productive functions (Figure 6):

- Protection. Forest areas designed primarily to obtain indirect benefits, generally on land susceptible to erosion, land that can act as barriers to protect urban settlements from avalanches or floods, riverside land to prevent floods or land where the aim is to promote fauna and flora to increase the specific diversity or generate ecological corridors between isolated populations.

- Production. Forest stands whose main purpose is to obtain direct products, whether timber, resin, cork, fruit, firewood, or any other commercial products. Under the **MAIL** project guidelines, the "new" forest areas will only have carbon sequestration purposes. However, in order to keep the forest, stand in balance away from pests and diseases or fires, intermediate products will probably be generated as a consequence of silvicultural activities such as pruning, thinning, or fire prevention treatments. In this sense, technological advances are already making easier the transformation of woody biomass residues and wastes into circular and innovative climate-friendly materials and products. It is possible that, even in the case of forests growing on land currently considered marginal, the species selected for reforestation may find their climax habitat and have good growth, in which case there may be a quality timber harvest. If so, and following the indications of the European Commission, the wood products generated will

be obtained in a sustainable way and with a long-life cycle, which will contribute to achieving climate neutrality by storing carbon and thus replacing fossil materials. In particular, because its embodied carbon in furniture, building materials, and everyday object, adds to the carbon removal that would otherwise take place through biological processes.

Another important aspect of reforestation or afforestation is how it is performed. The process of natural reforestation is based on the sprouts from nearby trees or rooting of seeds without human intervention; however, it is slow and insufficient and must be complemented with other techniques when the replacement of trees involves human participation (Mohan *et al.*, 2021). In the case of marginal lands, natural reforestation is not contemplated since these are areas that have remained for a long time without tree cover or with such limited tree cover that natural regeneration in adequate quantity and quality has failed. Therefore, we assume that all potentially marginal lands will be reforested or afforested. The choice of each reforestation method will depend on several factors (Figure 6) related to the location of the area to be reforested (climatic peculiarities of each region), the economic resources available, the predecessor events of the reforestation or the predecessor land use to the afforestation.

- Location. The location of the reforestation/afforestation is one of the most important factors since it will determine the species to be used depending on the climate (there are species whose probability of growing by seed is very limited), the initial tree density considering the expected seedling mortality or seed germination success, the soil preparation considering the physicochemical characteristics of the soil, and in logistic terms, the accessibility to the area, the distance to communication routes and towns which will facilitate both the reforestation/afforestation and the control in the future.

- Economic resources. The reforestation/afforestation with seeds implies a lower cost since it employs less staff, is faster, and can cover large extensions, although it requires control of predatory fauna and generally has a lower success rate of reforestation than plantations. Depending on the size of the area under treatment, reforestation/afforestation will be slower and require more staff, but on the other hand, it ensures a much higher seedling survival rate and generates jobs.

- Predecessor events of reforestation. This should be considered if the reforestation is to be carried out on land that has suffered catastrophic events

such as fire, runoff, windstorms, or snowstorms, among others. For example, in burned lands, broadcast seeding will probably be a good method of reforestation since predators are absent, there is no competition with pre-existing vegetation and the soil has superficial fleeting fertilization (Serrada, 2011). Another example is when there have been windstorms, where the best option would probably be to eliminate the fallen and dead vegetation and take advantage of the light spaces in the canopy to introduce different species that generate changes in the vertical structure of the vegetation through a plantation since the seedlings would enter into great competition with the pre-existing vegetation.

- Predecessor land use to the afforestation. Depending on the use of the land on which the afforestation is to be carried out, different considerations will have to be taken into account. If, for example, afforestation is to be carried out on previously fertilized cropland, the trees will have greater availability of nutrients in the soil, as opposed to those areas with crops that were not fertilized. Another example is pasture land, which tends to be more degraded than cropland, especially if it is older pasture, as it has low fertility and high soil compaction, reducing soil aeration and biological activity (DiRocco *et al.*, 2014). Cultivation cycles also play a role, since the less the land has been cultivated, the less it has been degraded and better quality of the site for tree growth.

As there are different purposes with reforestation/afforestation, different locations with different rainfall and temperature regimes, and different soil backgrounds, the best trees for reforestation/afforestation will also be different (Figure 6). Considering all the influencing factors some species will be the most carbon sink, some will be the fastest-growing, some will be the best adapted to the ecosystem, and some will be the species that can grow in the shelter of others, or not. Consequently, we could say that there is no universal answer to determine the most suitable species, but some alternatives will be given in the guidelines.

5.4   Guidelines

These Guidelines are intended to be used at the Pan-European level in reforestation or afforestation programs on marginal lands with the main objective of carbon sequestration and reduction of CO2 emissions, and in certain cases will include the production of woody biomass or timber. The Guidelines form a set of recommendations for voluntary use and have been elaborated for different actors whether they are companies,

agencies, or stakeholders interested in ML management providing guidance on environmental, economic and social aspects.

These guidelines aim to address the needs set out in the new EU Forest Strategy 2030, which aims to increase forest cover, restore EU forests, ensure resilient and multifunctional forest ecosystems, combat climate change, increase the rate of carbon sequestration at the European level with the objective of being climate neutral and support the socio-economic functions of forests in rural areas, boosting the forest bio-economy within the limits of sustainability.

5.4.1 General guidelines

1. Pan-European criteria and indicators for sustainable forest management should be used as a general framework for ML reforestation/afforestation programs. All criteria taken in the reforestation/afforestation project should be consistent with the economic, social, and environmental approaches proposed by the New EU Forest Strategy for 2030.

2. In addition to these guidelines, national policies and programs related to forests, forestry, biodiversity, climate change, energy, land use, depopulation, agriculture, and integrated watershed management should be taken into account.

3. Clear administrative responsibilities should be established within each of the EU countries concerning ML reforestation/afforestation programs.

4. The economic, environmental, social, and cultural impacts generated by the reforestation/afforestation of ML should be evaluated, as appropriate in each country, through environmental assessment mechanisms and approved by local communities. Also, reforestation/afforestation areas should be included in national monitoring plans to evaluate the different impacts on the carbon balance.

5. Forest management of ML reforestation/afforestation projects should be climate and biodiversity-friendly, keeping the use of woody biomass within the limits of sustainability and encouraging efficient utilization of wood as a resource, in line with the cascading principle[5].

6. Forest management should be carried out using a model and intensity that maintains the forest's biodiversity, regenerative capacity, vitality, and productivity,

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[5] The cascade principle was already presented in the EU Forestry Strategy 2014-2020. According to this principle, wood is used in the following order of priorities: 1) wood-based products, 2) extending their service life, 3) re-use, 4) recycling, 5) bio-energy and 6) disposal (European Commission, 2021a).

and also has the potential to fulfill, now and in the future, the ecological, economic, and social functions relevant at local, national and global scales, and that does not cause damage to other ecosystems [6].

7. Reforestation/afforestation in ML will follow practices that rehabilitate biophysical constraints related to soil and land conditions while improving environmental, economic, social, and operational aspects of the value chain.

8. In marginal areas, projects that benefit climate change mitigation through carbon sequestration, conserve biodiversity, control erosion and desertification, and generate a timber product should be promoted.

9. Reforestation/afforestation areas under woody biomass and timber production system with fast-growing species must be managed under sustainable management parameters.

10. Before starting the reforestation/afforestation of the ML it is pertinent to have the historical knowledge of the local community about the target land to be planted.

11. ML reforestation/afforestation projects should contribute to maintaining or enhancing the provision of ecosystem benefits and services at the landscape level

12. ML reforestation/afforestation projects should be implemented to prevent the impacts of natural hazards (landslides, wind, storms, etc.) on human settlements and infrastructure.

13. The success of the reforestation/afforestation project depends on increasing public knowledge of the sustainability issues related to the "new forest" and its potential benefits in environmental, social and economic terms.

5.4.2 Socio-economic guidelines

14. Reforestation/afforestation projects should follow circular economy principles, promote rural development, and cross-sectoral coherence between the forest and other relevant sectors such as agriculture, industry and energy.

15. ML reforestation/afforestation projects should enhance and encourage rural development and revitalize the economy of the most depopulated areas. To this end, whenever possible, local landowners and other relevant stakeholders should be included in decisions, and operators, contractors and workers should be sought out in nearby areas.

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[6] Retrieved from the New EU Forest Strategy for 2030, subchapter 3.2 "Ensuring forest restoration and reinforced sustainable forest management for climate adaptation and forest resilience".

16. Reforestation/afforestation of communally managed MLs should be prioritized over MLs managed by companies, in order to guarantee distribution of benefits.

17. When appropriate, it would be necessary to evaluate the subsidies and incentives that each country or region grants for this type of rural action.

18. Companies interested in environmental compensation areas and public institutions that finance these types of projects should only support proposals that are environmentally robust over time, economically viable, culturally accepted and socially equitable.

19. Forest managers will try to reconcile collective interests with the interests of private forest owners in the economic use of natural resources and environmental protection through knowledge transfer and awareness-raising actions.

20. Local communities should be involved in the decisions of the reforestation/afforestation projects of ML by analyzing their needs and concerns.

21. When reforestation/afforestation is carried out in the surroundings of urban areas, it is necessary to analyze the landscape and cultural value that it will bring to the population.

22. When reforestation/afforestation is carried out in the surroundings of protected areas (for biodiversity or architectural heritage), it should be considered the elaboration of planning of forestry activities following the policies subscribed by these protected sites.

5.4.3   Environmental guidelines

23. When reforestation/afforestation is carried out in irrigated agricultural areas, an analysis of the positive and negative impacts that the trees will have on the water cycle will be carried out. In situations of water deficit in the territory, species with lower water requirements shall be chosen.

24. When selecting sites for reforestation/afforestation projects, environmental impacts on areas of high ecological value should be taken into account. If the area involves the conversion of shrub and grassland areas to a forest, the impacts on the existing fauna and flora will be analyzed.

25. Reforestation/afforestation activities in ML that contribute to the improvement and restoration of ecological connectivity between isolated populations of vegetation and fauna should be promoted.

26. Trees should be planted and managed to respect all ecological principles. This means that the right species should be planted in the right place for the right purpose. This requires initial planning and long-term monitoring.

27. A precautionary approach should be adopted in the use of genetically modified trees and in the case of their use, reforestation/afforestation projects should be associated with an assessment of the ecological, socioeconomic and cultural impacts, including long-term effects.

28. Self-sustainable projects should be created with species adapted to the site, without the need to use chemicals or other products that negatively impact soil, water resources and biological diversity.

29. Priority will be given to a mix of species, genetically and functionally diverse, with different biotic and abiotic sensitivities and recovery mechanisms after disturbances, diseases or pests, rather than monospecific afforestation.

30. In terms of risk management, the fire risk in the reforestation/afforestation ML will be evaluated considering national or regional forest fire protection plans.

31. Efficient tools and devices for fire prevention and extinction will be articulated to maintain the carbon accumulated in the forests and thus mitigate climate change.

5.4.4   Specific forest management guidelines

32. An initial reforestation/afforestation project management plan will be developed based on the purpose of the reforestation/afforestation project: protection (restoration after illegal deforestation, harvesting, forest fires) or production.

33. Once the afforestation/ reforestation management of the ML has begun based on the initial plan, it will be adaptive management so that there is a continuous improvement of silvicultural activities, adapting the management of the forest to the climatic requirements.

34. When the area to be reforested or afforested should be very large, a silvicultural management plan should be drawn up to control the carbon balance accumulated in the forest.

35. Fire prevention and alert plan will be implemented to reduce the impact of fire on forest health, particularly in the Mediterranean climate.

36. Forest health monitoring and periodic pest and disease detection will be carried out using technologies such as satellite remote sensing.

37. Site-specific allometric equations derived from local destructive sampling or from national forest inventory data, if available, should be used to calculate carbon content. The choice of the correct allometric equations is critical as they can significantly affect the estimation of carbon stocks.

38. Depending on the land cover or use where the reforestation/afforestation project is to be established, it will be necessary to carry out a series of preliminary activities to eliminate existing vegetation (clearing, mowing, weeding, etc.), and soil preparation activities (subsoiling, terracing, etc.).

39. In agricultural areas, depending on the characteristics of the terrain and the level of soil compaction, it will be necessary to undertake tillage, linear subsoiling, full subsoiling, hand augering, helicoidal augering or backhoe augering.

40. Native species should be chosen, whose seed or planting stock comes from varieties and ecotypes that are well adapted to the project area, thus supporting diversity and resilient adaptation to climate change.

41. Regardless of the cultural characteristics of the species, the plants chosen must be compatible with those of the season or afforestation site, and the objective of the reforestation/afforestation must be taken into account when choosing the species.

42. In the case of protective reforestation/afforestation, which is applied in very degraded soils, with serious deficiencies in water retention capacity, fertility, and permeability, the species chosen should be those that can coexist with these factors in their first ages (frugals and xerophytes).

43. The reforestation/afforestation with species, varieties, provenances or ecotypes from outside their natural area of distribution shall be avoided whenever possible, and shall only be used when their introduction does not endanger native ecosystems.

44. The reforestation/afforestation with invasive alien species shall be avoided following the CBD Guiding Principles for the Prevention, Introduction, and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species.

45. The initial reforestation/afforestation density will be analyzed based on silvicultural factors (temperament, regrowth capacity, size, carbon fixation capacity) and economic factors (objective, cost of operations, thinning forecast and timber market).

46. Tolerant species are introduced at higher densities, as they tolerate competition better and natural pruning is encouraged, i.e., the lower branches die off naturally, resulting in straight, taller stems.

47. In protective reforestations/afforestations, the initial density should be higher, since the aim is to achieve a complete cover as soon as possible. On the other hand, for producers, the initial density will be lower, since the increase in profitability depends on minimizing treatment costs.

48. In the first 2-4 years of afforestation, dead plant replacement operations shall be carried out. The operative method will always be manual, even if the original afforestation was done mechanized or simultaneously with soil preparation. For slow-growing species, the fails can be replaced until the third or fourth year of afforestation. With fast-growing species, the fails should be replaced the following year of afforestation.

49. Whether the reforestation/afforestation method is seeding or plantation, in the early stages of the project, grazing and predatory fauna will be limited using protective tubes or nets.

50. To ensure the environmental and socio-economic viability of forests, continuous and non-coetaneous canopy silviculture shall be practiced, maintaining dead wood quantities, regulating wildlife densities, and creation of protected habitat plots or reserved areas in production forests.

51. In ML afforestation/reforestation projects, trees selection fellings, selective cutting, non-intensive thinning, and nutrient management will be prioritized.

52. Through light thinning, carbon can be increased by reducing competition for biological stability, improving the health status of the stand, and thus increasing the value and size of the products.

53. Cleared vegetation is applied as a mulch, which protects the soil from erosion, reduces soil temperature and moisture loss, and improves carbon conservation.

54. Silvicultural treatments will be carried out to reduce the fuel load and the vertical and horizontal continuity of the vegetation, thus increasing the resilience of the vegetation to fires, pests and diseases.

55. Silvicultural treatments should be designed to maintain a structural diversity, preserving young trees resistant to windstorms or snowstorms, mature trees more resistant to drought and frost, or an adult and intermittent tree cover that favors the growth of understory species.

56. Selective thinning or free thinning will be prioritized as a silvicultural management method to allow the preservation of desired species and to generate spaces for planting regrowth species that can accelerate natural processes.

57. In areas where reforestation/afforestation is carried out and tree vegetation is present, fire-prone species will be selectively thinned and regrowth species that are resistant to fire and have high carbon sequestration rates will be planted. This situation can also occur in the successive stages of reforestation/afforestation projects to increase the resilience of the vegetation to fire.

58. To maintain the carbon accumulated in forests and thus mitigate climate change, the cutting cycle should be prolonged as much as possible. However, the specific composition of the afforestation should be regulated or maintained and the stand should be prepared for natural regeneration.

6. MAIL PLATFORM FOR MARGINAL LANDS MANAGEMENT

MAIL Map Portal is an online tool developed within MAIL project to present dynamic maps and provide interactive tool – Decision Support System which facilitates the end-users and stakeholders utilization of project outcomes in the processes like: marginal land identification, management, afforestation planning and analysing.

MAIL Map Portal contains various functions which allow inter alia:

- identify marginal lands (using 2 approaches: based on databases or on satellite imagery classification)
- classify marginal lands in 3 classes (from the most suitable to unsuitable areas for afforestation)
- identify the most suitable tree species for given area
- calculate the amount of carbon which can be sequestrated in the future
- plan afforestation programs and calculate their costs.

Various solutions were developed within number of tasks of MAIL project and implemented mainly in Task 2.9 and 3.4, but not exclusively. Part of Task 5.4 was to design and implement a decision support system and fine-tune the solution implemented within Task 3.4. In order to do that, new structure of MAIL Map Portal was designed to combine all the tools prepared within other tasks (Figure 7). It required the following steps:

- functional tests of each tool to identify if they work correctly under various circumstances and options selected by users and various areas of interest within Europe

- identification of potential conflicts in the name conventions (the tools were implemented by various Secondees and may use the same name of the variables)

- redesign of tools functionalities to adjust them as elements of more complex solution

- design the workflow and processing scenarios – how results of on tool can be used in the following tools

- layout optimization to provide clear and easy to understands commands and options for users with short descriptions of each tool main functionality

- performance optimization – some tools perform huge amount of data processing which has to be done on the flight to provide the results according to user's settings.
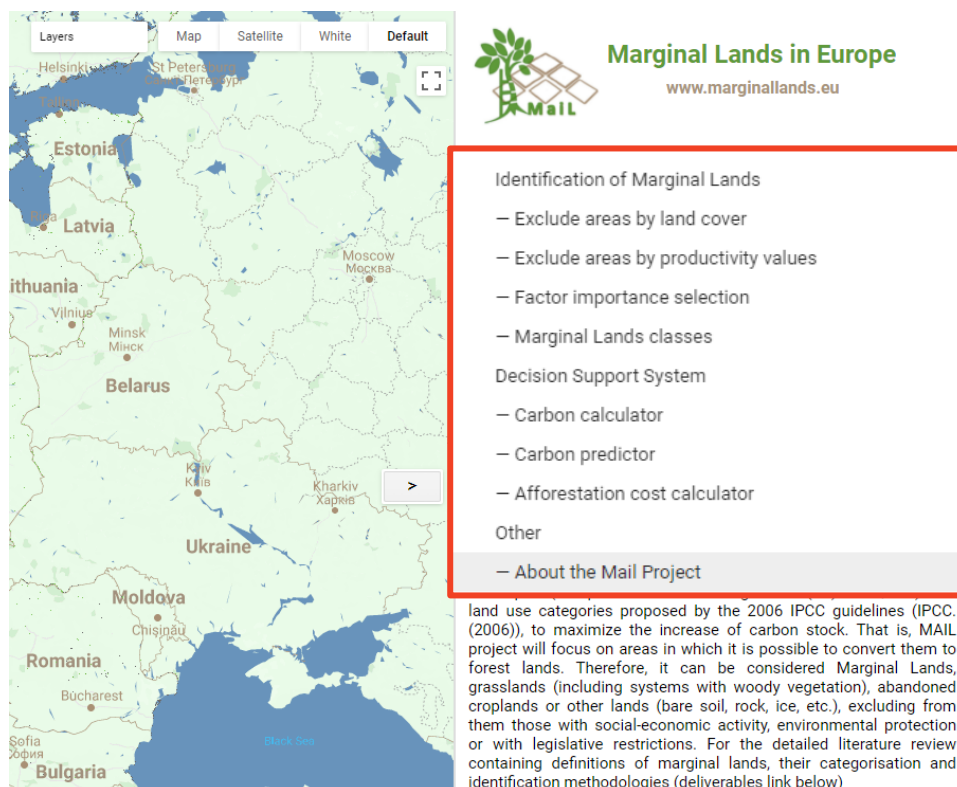
Figure 7. Panel with redesigned tools developed within MAIL project and available in MAIL Map Portal.

To facilitate the usability of *MAIL* Map Portal two types of materials have been prepared:

- manual – pdf document with description of each tool functionality and references to the specific project deliverables or research papers were all details about applied solutions may be found
- tutorials – video materials presenting the tools and examples of usage in real case studies. Videos are available as a module of MAIL MOOC.

Link to the portal is available on project website: http://marginallands.eu.

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ANNEX I: TABLE OF FIGURES

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ANNEX III: FOREST PAYMENT SOFTWARE AVAILABLE IN THE MARKET.

Forestry software	Price	Description
ArborCAD	Perpetual license: $4,490 Monthly license: $299	ArborCAD is a CAD solution used by arborists for creating, editing, and evaluating tree placements and grooming designs. ArborCAD allows to automatically produce professional drawings to local and international standards anywhere in the world.
ArborLine	Not provided by vendor	ArborLine is a tool that helps utility arborists reduce time spent on choice of equipment and work site documentation.
ArborPLUS	Not provided by vendor	ArborPlus is a web-based tree care software that streamlines communications between arborists and their clients.
ArborSite	Not provided by vendor	ArborSite is a tree inventory and risk tracking software that helps arborists monitor work actions needed to be performed on trees and their costs.
ArboStar	Not provided by vendor	ArboStar is a complete cloud-based business management solution developed for the unique challenges faced by tree care and landscaping businesses. Intuitive and easy to use software integrates the modules and management tools you will need to grow your operation and optimise your level of service.
Arb Pro	Monthly license: £60	Arb Pro is a web-based CRM solution that lets tree contractors easily manage sales process with minimal paperwork, phone calls, and site visits. Arb Pro uses managing Quotations, invoices, tools, risk assessment and so much more is possible.
Assisi Inventory	Not provided by vendor	Software for processing an ongoing inventory of timber, down woody debris, vegetation and regeneration.

Forestry software	Price	Description
BUCKPRO	Not provided by vendor	The Bucking Improvement System develops bucking rules for the cut-off saw operators, by defining desired bucked lengths for different input lengths and diameters.
Clearion VM	Not provided by vendor	Clearion VM is a vegetation management solution that improves the effectiveness of transmission and distribution line clearing programs for arborists. With Clearion Vegetation Management (VM) solution you can create detailed work plans, issue paper or electronic work orders, track post-work inspections and rework, calculate estimated and actual costs, and manage schedules and budgets.
Trimble Connected Forest	Not provided by vendor	Production planner end-to-end forestry operations and business processes associated with Planning, Planting, Growing, Harvesting, Transporting and Processing.
CruiseCalc	Perpetual license: $379	Timber volume report production.
Cruise Control	Not provided by vendor	Cruise Control can collect just Species, DBH and merchantable height or it can collect things like Plot Level information, tree grades, codes (user defined), product assignments in 1-, 2- or 8-foot increments and much more.
CTL-SIM	Not provided by vendor	Cut-To-Length Harvesting Simulation Program, is a comprehensive simulation program that allows accurate modelling of cut-to-length harvesting operations.
Custody Manager	Not provided by vendor	Create Barcoded Trip Tickets with GPS in the Woods
DTAILS	Perpetual license: $1,500 Monthly license: $100	DTAILS is a comprehensive lumber inventory control software package intended to meet the needs of any lumber-based company from sawmills to resellers.

Forestry software	Price	Description
eLIMBS	Not provided by vendor	eLIMBS is a Software Solutions and Hardware Solutions provider serving the wood products industry with easy-to-use tools for tracking wood products from the initial standing timber process clear through the harvesting, production and manufacturing process up to and beyond the point of sale.
Enfor Appraisals	Not provided by vendor	Enfor Appraisals is a timber stumpage appraisal software.
Forest Metrix	Not provided by vendor	Forest Metrix gives instant summaries in the field, including the charts and tables you include in your management report.
Forest Products Accounting	Not provided by vendor	Forest Products Accounting is designed for loggers, wood dealers, sawmills, chip mills, pulp and paper mills, OSB mills, biomass plants, pellet mills, plywood plants, and veneer mills.
HRIS by Tesera	Not provided by vendor	Tesera's high resolution inventory solutions are a blend of area-based (using LiDAR, colour infrared imagery, ground plot data, complimented with terrain and climate data) and individual tree crown delineation to provide a comprehensive and reliable inventory solution.
iCruisePro	Perpetual license: $1,295	iCruisePro is a timber inventory software.
i-Tree	Free	The i-Tree Tools is a forest management tool that quantifies the structure of trees and forests, and the environmental services that trees provide.
Logged it	Not provided by vendor	Logged it manages timber harvesting.
Lumber Inventory	Not provided by vendor	A lumber tracking application with real-time order tracking, production reports and kiln activity.

Forestry software	Price	Description
MapCentrix	Monthly license: $95	MapCentrix helps organise your staff, map trees, and capture tree photos with arborist management solution accessible from any device.
MBG Cruise	Not provided by vendor	Application for collecting forest inventory data on a hand-held data recorder.
MosaicMill	Not provided by vendor	MosaicMill has developed tree wise forest inventory method and will start providing processing services in May-June 2018. No traditional field measurements are required - in this novel methodology each tree is located and measured from UAV data. Especially suitable tree inventory is for small and medium size forest properties. MosaicMill inventory method is applicable for both plantations and managed natural forest.
Rezatec	Not provided by vendor	Applies data science to satellite imagery and geospatial data to deliver cloud-based analytics
RoadEng Forest Engineer	Not provided by vendor	Complete road and site design software designed specifically for forestry. Good engineering can reduce the costs associated with road building and logging. Proven and field-tested, our software is used by thousands of consultants, companies, universities, and governments worldwide.
SGF/My Forest	Not provided by vendor	SGF Forest Management System is an integrated system for operations and support for forestry decisions. Plan and control all stages of the productive chain monitoring physical and financial variables. Simulate scenarios, set targets, calculate costs, compile incomes and generate performance kpis.
SmokeD	Not provided by vendor	Wildfire detection through machine learning.
Supergeo Forest Inventory App	Not provided by vendor	Forest Inventory App is an Android application specially designed for foresters and other natural

Forestry software	Price	Description
		resource managers to collect data in the woods. This app assists surveyors to record customised data efficiently throughout the timber cruising.
TallyWorks	Not provided by vendor	TallyWorks Lumber can be used in integration with TallyWorks Logs or as a standalone application for managing all states of lumber inventory and sawmilling operations including all the value-added processes you undertake.
TCruise	Not provided by vendor	TCruise is a comprehensive desktop forest inventory solution for conducting forest inventories. The NEW TCruise Pro program features several optional modules for advanced cruise design and analysis
Terrain Tools Forest Engineer	Not provided by vendor	Terrain Tools® Forest Engineer is a software toolkit for 3D mapping, terrain modelling and land development. Terrain Tools® includes a variety of 3D mapping functions, as well as engineering design functions, including cable and deflection line analysis.
Tree Plotter	Perpetual license: $1,500	TreePlotter™ INVENTORY is used globally as a comprehensive GIS software application for field data collection and inventory data management. But the value of INVENTORY is so much more: dashboard, standard and configurable reports, complete work history, advanced queries on datasets, map sharing, and customised account administration.
Tree Tracker	Not provided by vendor	Tree inventory management and risk assessment
Vegetation Management	Not provided by vendor	Vegetation Management is a utility mapping solution that supports vegetation management planning, tracking, and execution.

ANNEX IV: FOREST FREE SOFTWARE EXAMPLES

Forestry software	Developer	Description
Agroforestry Production Development Tool	UBC Farm in partnership with Brinkman & Associates Reforestation	Agroforestry Production Development Tool (APD Tool) is a decision making and planning tool developed with input and feedback from stakeholders including farmers, consultants, and other experts. The tool helps assess many levels of new agroforestry endeavours, including environmental, social, and economic considerations, labour and cash flow planning.
Buffer$: a conservation buffer economic analysis tool	Bentrup, G.	This Microsoft Excel-based tool can be used to analyse cost benefits of buffers compared to traditional crops.
CAPRA (Computer Assisted Pest Risk Analysis)	EPPO Secretariat	This software aims to assist pest risk analysts in running the EPPO decision-support scheme for Pest Risk Analysis (EPPO Standard PM 5/3(5) Decision-support scheme for quarantine pests), and other decision-support schemes.
Collect Earth	openforis	Collect Earth is a tool that enables data collection through Google Earth. In conjunction with Google Earth, Bing Maps and Google Earth Engine, users can analyse high and very high resolution satellite imagery for a wide variety of purposes, including: Support multi-phase National Forest Inventories; Land Use, Land Use Change and Forestry (LULUCF) assessments; Monitoring agricultural land and urban areas; Validation of existing maps; Collection of spatially explicit socio-

Forestry software	Developer	Description
		economic data; Quantifying deforestation, reforestation and desertification.
Forest assessment tool and simulator	FAO	The Forest Assessment Tool and the Forest Simulator are free Excel applications for local-level (e.g. village) forest assessment and planning. The Forest Assessment Tool is a simple application for storing forest assessment data collected from field sample plots and for computing key results for this assessment. The Forest Simulator can be used to project forest development under different harvesting regimes uses results derived from the assessment module as the input data.
Heureka - Software for forestry planning and analysis	Swedish University of Agricultural Sciences	The Heureka system allows the user to perform a larger amount of different analysis and management plans for forestry. The system can perform short- and long-term projections of timber, economy, environmental conservation, recreation, and carbon sequestration. Heureka is a powerful system with multiple functions.
NettiMELA - an analysis tool for forest management planning at the internet	Finnish Forest Research Institute	MELA is an operational decision support system developed and maintained by Metla based on its forest research. The service is intended for forest organisations responsible for the management of large forest areas as well as for service providers in forest management planning. Via Internet NettiMELA transfers research results into practical forestry and its planning systems fast and effectively. MELA is a general

Forestry software	Developer	Description
		analysis tool for forest management planning.
RILSIM, Reduced-Impact Logging SIMulator	Blue Ox Forestry	RILSIM, the "Reduced-Impact Logging SIMulator", is a financial modelling software developed as a service to the international forestry community. RILSIM has been designed to permit users to rapidly estimate the costs and net revenue associated with logging operations in order to compare short-term financial costs and returns expected from reduced-impact logging with those expected from conventional logging under identical local site conditions. The purpose of the software is to help users learn about reduced-impact logging and its potential financial advantages as compared to conventional logging.
US Forest Service - Tools and applications	US Forestry Service	The US Forestry Service has a web section dedicated to software (and online tools) that can be use as decision support and planning tools.
VERITAS - Timber volume calculator	Kometter, R.	The VERITAS Timber Volume Calculator (VERITAS Calculator) is an electronic application designed to calculate in a practical and timely manner the relationship between the standing timber volume of a tree and its expected timber volume of sawn wood per grades according to the NHLA grading rules. The application provides electronic calculations of timber volumes for each tree using the Diameter at Breast Height (DBH) as a single variable.

ANNEX V: REVIEW OF PAPERS ON ML DETECTION

Title:	A Review of the Application of Remote Sensing Data for Abandoned Agricultural Land Identification with Focus on Central and Eastern Europe

Author:	Tomas Goga et. Al, 2019	**Time Period:**	1992-2019

Sensor:	Landsat 7 and landsat 8 with combination of MODIS data, LULC land cover data, SAR dataset
Area of interest:	Most of the studies were localized in Europe, North America, Russia, and China. Some studies investigated localities in Southeast Asia, Central Asia, the Sub-Saharan area of Africa, and equatorial South America.
Objective:	This study aims to analyse and assess studies published from 1992 to 2019 and listed in the Web of Science (WOS) and Current Contents (CC) databases, and to identify agricultural abandonment by application of remote sensing (RS) optical and microwave data.
Method:	Object based image analysis and multitemporal analysis. Has used combination of NDVI + OBIA, NDVI+ MA, SVM with OBIA and MA, RF.

Title:	Changes in agricultural land use in Estonia in the 1990s detected with multitemporal Landsat MSS imagery

Author:	U Peterson & R Aunap, 1998	**Time Period:**	1990 and 1993

Sensor:	Changes in agricultural land use in Estonia in the 1990s detected with multitemporal Landsat MSS imagery.
Area of interest:	Estonia
Objective:	To detect change in agriculture land use in Estonia using Landsat MSS imagery.
Preprocessing:	Classifying terrestrial environment and water using NIR reflectance, secondly classifying forest and non-forest areas.
Method:	Comparing spectral reflectance in suitable scene i.e. Spring ,Winter and mid-summer (June) using NIR to red ratio

Results:	Arable land can be found intermittently across Estonia, while it is concentrated more densely in some locations than in others. According to Laasi's land-use review in 1925, the basic pattern of distribution has not changed considerably since the turn of the century (1933).

Title:	Cross-border Comparison of Postsocialist Farmland Abandonment in the Carpathians		
Author:	Tobias Kuemmerle, 2008	**Time Period:**	1986,1988 and 2000
Sensor:	Landsat TM/ETM+ high resolution images		
Area of interest:	Border triangle of Poland, Slovakia, and Ukraine		
Objective:	To detect land use change process such as farmland abandonment.		
Preprocessing:	All images were geometrically rectified, relief displacement corrected with a digital elevation model from the Space Shuttle Radar Topography Mission, and co-registered to the Universal Transverse Mercator coordinate system. For atmospheric corrections, the 5S radiative transfer model was employed.		
Method:	Support vector machines (SVM) one against all strategy. They used 7,789 training pixels based on 1,079 ground truth locations. It is a time series analysis.		
Validation:	They calculated an error matrix, overall and class-specific classification accuracies, and the kappa value.		
Results:	Has overall accuracy of 90.9% and a kappa of 0.82. Farmland was most extensive in Slovakia among three countries. Reforestation was lowest in Ukraine		

Title:	Greening trends and their relationship with agricultural land abandonment across Poland		
Author:	Natalia Kolecka, 2021	**Time Period:**	1986–2019

Sensor:	Annual Landsat derived NDVI
Area of interest:	Poland
Objective:	Objective of this research was to investigate whether long-term gradual greening of agricultural land can aid in mapping abandoned land across Poland.
Preprocessing:	The main source of data for this study was the Landsat 5, 7, and 8 imaging archives, which were accessed through the Google Earth Engine (GEE) service. The Landsat 4–7 Surface Reflectance Code (LEDAPS) and Landsat 8 Land Surface Reflectance Code (LaSRC) algorithms were used to create the surface reflectance (SR) datasets. A cloud, cloud shadow, water, and snow mask, as well as a per-pixel saturation mask, were included with the SR data output. In addition, abandoned land in Poland is greening more and more intensively than managed land, according to this study.
Method:	It has two approaches :1) Using **Non Parametric Tren**d analysis by applying Mann Kendall and Thiel -Sen Median slop estimator ab were assessed at 95% confidence level. 2) Using Temporal Segmentation method called **LandTrendr** using Google Earth Engine with P value < 0.05
Validation:	Using HansenTree cover map for 2000, version 1.0
Results:	The results from the NPT analysis and the LTR method applied to the1986–2019 annual Landsat NDVI mosaics showed NDVI increases across Poland, but they differed noticeably. Both method concludes indicating greening of 12.1 % in Poland. The NPT analysis indicated widespread greening (high greening rates) mainly in the Carpathian Mountains located in southern Poland in two stripes with approximately north–south orientation, and in the very north-east of the country. LTR is more liberal than LTR.

Title:	Mapping abandoned agricultural land in Kyzyl-Orda, Kazakhstan using satellite remote sensing		
Author:	Fabian Löw	Time Period:	2009 - 2014
Sensor:	Landsat and Rapid Eye images		
Area of interest:	Southern Kazakhstan		
Objective:	To map and analyse agricultural land use in the irrigated areas of Kyzyl-Orda, southern Kazakhstan, Central Asia.		
Preprocessing:	A vector data was created as appropriate number of satellite images were not available from soviet union. SPOT and Google Earth high resolution images were used to digitise objects and create a vector data. • For satellite data, images were co-registered to two high resolution SPOT-5 from 2011. Atmospheric correction is performed using ATCOR-2. • For vector data, digitization of 66281 field objects was performed. • For 2011, campaign have been conducted to collect field data with GPS camera using geo location data with accuracy of 2-3 m.		
Method:	(i) generating a vector data base of all ever used fields in the study region, (ii) generating land use maps for 2009-2014, (ii) creating a multi-year land use archive for each field object and (iii) analysing the LCT (land cover trajectories) in relation to the vector database representing all, ever-used agricultural field objects. • Object based classification: Using RF and SVM.		
Validation:	It was validated through second independent test set which contained 250 field samples for abandoned land and actively used fields. The length of the observation period, i.e. the number of consecutive years, needed to generate reliable results using the suggested LCT analysis was also explored using the second test data set. The LCT analysis was compared to single-year evaluations of land abandonment, where shrubland and bare soils were deemed to be abandoned land and rice fields were assumed to be active land.		

	• Object based analysis: Confusion matrix using Zero scores test.
Results:	The total accuracy of both methods ranged from 0.843 to 0.908, although in four of the five years, the RF was somewhat more accurate than the SVM. The fusion strategy produced much more accurate findings (at the 95 percent confidence level) than either RF or SVM alone. The non-overlapping confidence intervals of the fusion on the one hand, and RF or SVM on the other, also demonstrate this. When compared to RF or SVM, decision fusion resulted in a gain in overall accuracy of up to 7%, with high overall accuracies in all years (0.936 - 0.979).

Title:	Mapping agricultural land abandonment from spatial and temporal segmentation of Landsat time series		
Author:	He Yin et al.	**Time Period:**	1985-2015
Sensor:	Landsat data		
Area of interest:	Caucasus, covering parts of Russia and Georgia		
Objective:	Using geographical and temporal segments taken from Landsat time series, they set out to develop a new method for detecting the extent and exact timing of agricultural land abandonment.		
Preprocessing:	atmospheric correction and radiometric calibration using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) for each USGS and ESA Landsat image, also applied FMASK to mask cloud, cloud shadows and snow for each image.		
Method:	Using a multiresolution segmentation approach, they first created agricultural land image objects from multi-date Landsat images. Second, using Landsat temporal-spectral metrics and a random forest model, they calculated the chance that agricultural land was used each year for each object.		
Validation:	Produced confusion matrix and visual interpretation using high resolution imagery from google earth and bing aerial , they used visual time series tool HUB Time Series Viewer for validation		
Results:	This method could successfully differentiate abandoned agricultural land from active agricultural, recultivational and fallow		

	land. Overall accuracy is 97 + or -1 for object based analysis and 82 + or - 3 for pixel based analysis.

Title:	Mapping the extent of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data.		
Author:	Camilo Alcantara	**Time Period:**	2004-2006
Sensor:	MODIS normalized difference vegetation indices (NDVI) time series data (eight-day composites, 250-m resolution) from Terra (MOD13Q1 version 5) and Aqua (MYD13Q1 version 5).		
Area of interest:	Soviet Union (Central and Eastern Europe and the Balkan Peninsula, including 30 countries fully or partly).		
Objective:	To quantify the extent of abandoned farmland, both croplands and pastures, across the Soviet Union.		
Preprocessing:	They applied a Savitsky–Golay filter to the time series (2003–2009) and used TIMESAT 2.3 to calculate the (1) start of the growing cycle, (2) end of the growing cycle, (3) base NDVI, (4) maximum NDVI, (5) length of the growing cycle, and (6) centre of the growing cycle for each year.		
Method:	For training points, stratified random sample of 1000 MODIS pixels per target class within Landsat map was selected, SVM based on Gaussian Kernal was applied.		
Validation:	Visually interpretation using Landsat images, high resolution QuickBird images in Google Earth.		
Results:	Largest area of abandoned farmland occurred in Russia with 61% between 2003 to 2006		

Title:	Mapping the timing of cropland abandonment and recultivation in northern Kazakhstan using annual Landsat time series		
Author:	Andrey Dara	**Time Period:**	1988 - 2013
Sensor:	Landsat TM/ETM + OLI from USGS and ESA for years between 1984 and 2016		

Area of interest:	Kostanay Oblast in northern Kazakhstan and considerably smaller border areas of Russia.
Objective:	To develop a test a trajectory based mapping of cropland abandonment and recultivation in Eurasia's stepps focusing on northern Kazakhstan using Landsat imagery.
Preprocessing:	To begin, they used an AROP (Automated precise registration and orthocorrection software) to match ESA data with USGS data. Following that, the Function of Mask (FMask) technique is used to mask clouds and clouds shadows. For atmospheric correction, Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) was used.
Method:	To compensate data scarcity, they have used a temporal window of three years to generate spectral variability metrics. Within each moving window, they derived the per-pixel minimum, median, maximum, mean, standard deviation, and percentiles (5, 25, 75, and 95) for the red, green, blue, NIR, SWIR1, and SWIR2 bands. In addition, they also calculated the Normalized Difference Vegetation Index (NDVI), the Normalized Burn Ratio (NBR) and the Modified Soil-Adjusted Vegetation Index (MSAVI2) from which they derived the same metrics as for the six Landsat bands. Has used RF classification of cropland and non cropland areas. They trained RF model with reference data collected over stable croplands(areas that were permanently cropped between 1985 to 2015) and stable non croplands(areas that were never cropped) based on visual interpretation of Landsat time series and used a change detection algorithm LandTrendr that determines goodness of fit.
Validation:	It's based on a stratified-random selection of validation points produced from visually evaluating the Landsat time series and, if available, high-resolution imagery in Google Earth. It also used a fuzzy validation strategy to account for progressive spectral change, with a confidence interval of +/- 1 year.
Results:	Has achieved overall accuracy of 88.8 % using confusion matrix.