SEEMLA

Sustainable exploitation of biomass for bioenergy from marginal lands in Europe

SEEMLA Project Grant Agreement no. 691874

Guidebook of methodology to identify MagL and assess their availability in Europe; GIS model & Web-based application

28th February, 2017

I. About the SEEMLA project

The aim of the Horizon 2020-funded "Sustainable exploitation of biomass for bioenergy from marginal lands in Europe" (SEEMLA) project is the reliable and sustainable exploitation of biomass from marginal lands (MagL), which are used neither for food nor feed production and are not posing an environmental thread. The project will focus on three main objectives: (i) the promotion of re-conversion of MagLs for the production of bioenergy through the direct involvement of farmers and forester, (ii) the strengthening of local small scale supply chains, and (iii) the promotion of plantations of bioenergy plants on MagLs. The expected impacts are: Increasing the production of bioenergy, farmers' incomes, investments in new technologies and the design of new policy measures. FNR will coordinate the project with its eight partners from Ukraine, Greece, Italy and others from Germany.

Project coordinator

Agency for Renewable Resources Fachagentur Nachwachsende Rohstoffe e.V.	FNR	Germany

Project partners

Salix Energy Ltd.	SALIX	Ukraine
Institute for Bioenergy Crops & Sugar Beet of the National Academy of Agricultural Science	IBC&SB	Ukraine
Legambiente	LEGABT	Italy
Democritus University of Thrace	DUTH	Greece
Decentralised Administration of Macedonia and Thrace	DAMT	Greece
Brandenburg Technical University Cottbus-Senftenberg	BTU CS	Germany
Institut für Energie- und Umweltforschung Heidelberg GmbH	IFEU	Germany

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II. About this document

This report corresponds to D2.4 Guidebook of methodology to identify MagL and assess their availability in Europe; GIS model to identify location of MagL, provide their evaluation of basic criteria - Work Plan of SEEMLA. It has been prepared by:

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Work package	WP2
Task	T2.4 Common methodology development & design of a GIS approach for estimation of MagL availability in EU
Lead contractor for this deliverable	Democritus University of Thrace (DUTH)
Editor(s)	Spyros Galatsidas, Nikolaos Gounaris (DUTH); Wibke Baumgarten (FNR)
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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)	

Version	**Date**	**Author(s)**	**Reason for modification**	**Status**
1.1	2017-02-17	Spyridon Galatsidas, Nikolaos Gounaris, Elias Dimitriadis	Request for input from partners	finalised
1.2	2017-02-24	Spyridon Galatsidas, Nikolaos Gounaris	Integration of input	finalised
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III. Background

This deliverable "D2.4 Guidebook of methodology to identify MagL and assess their availability in Europe" is mainly based on the task as described in the Grant Agreement Annex I of the Horizon 2020 project SEEMLA (GA no. 691874), Task 2.4 Common methodology development & design of a GIS approach for the estimation of Marginal Lands (MagLs) availability in EU (Lead: DUTH, M1-12).

A challenge for the utilization of marginal lands is the solely missing knowledge of the availability of the latter by the different stakeholders. When numbers are available, these are often vague estimations. This task aims to develop a methodology to help identify the availability of any type of MagL. The development of a common methodology is based mainly on indicators derived from task 2.3. Furthermore, results from research projects about availability of MagLs, as well as databases and their estimations on availability of MagL in the EU are assessed.

This task also involves the development of a model that identifies a land parcel (or unit) as MagL (sub-categories) or not, combining all the available data of land into a single value. The model has the form of an application (web-based) that examines all land characteristics and determines whether they fulfill the criteria of the marginal land definition set in task 2.1.

In cases where spatial data are available this land characterization takes the form of a thematic map of marginal lands available for biomass exploitation. For these cases a GIS model based on the methodology described above has been designed. The GIS model will work as the technical and innovative "translation" of the results derived from tasks 2.1 to 2.3 and will facilitate future development in other regions. Thus, the GIS model has been developed in a sophisticated way that permits inputs of additional data and easy architecture modifications without causing inconsistencies. This will facilitate further development by incorporating results derived from WP4. The common methodology guidelines, web-based application and GIS model will be the basic elements for supporting the decision making by all types of stakeholders related to biomass production. They will also form the essential background for the development of SEEMLA tools in WP6.

Focus has been given to a European overview, although the common methodology in the form of a GIS model will be developed primarily for partner countries and will be tested during WP5 in pilot cases in order to give an estimation of the availability of MagLs in that specific regions. In addition by applying the GIS model to pilot cases a test on the SEEMLA tools, developed in WP6, will be performed.

Guidelines for the methodology and a basic GIS model for the EU countries will be provided but the development of a methodology ready for use from EU28 stakeholders is really an aspired task that exceeds the capacities of this project. The distribution and further use of this model after the end of the project should be secured in WP7.

The methodology has been developed in the concept worked out with IBC&SB and other partners, gathered in a GIS model by DUTH. Results will be further discussed and finalized in cooperation with the consortium, relying on their expertise and their national knowledge. The report of MagL availability assessment and the GIS model will be further processed and integrated in WP6 where the SEEMLA tools are developed.

Content

1 Identification of MagLs

Marginal lands are typically characterized by low productivity and reduced economic return or by severe constraints for agricultural cultivation. In the past decades, the concept of marginal land has been broadly applied to increase food security and support bioenergy production. However, the understanding and knowledge of marginal land assessment and management are limited and diverse (Kang et al. 2013b).

The definition of marginal lands depends heavily on their management goal and may include agricultural lands, forests, pastures or even urban sites (Lewis & Kelly, 2014). Therefore, the assessment of marginality for land use planning requires the investigation of multiple factors, as shown in Figure 1.

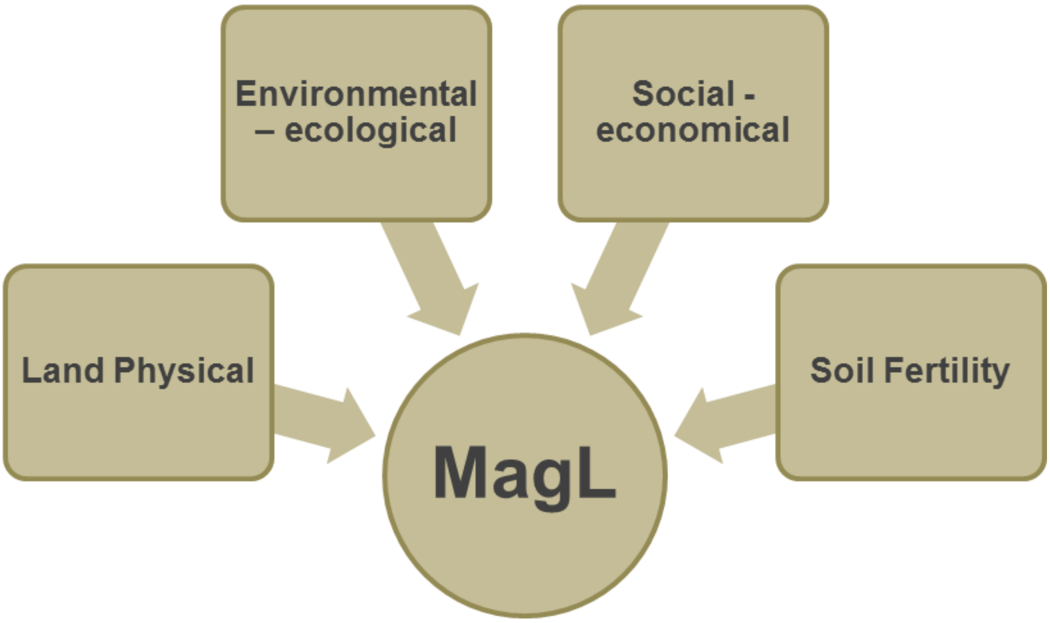

Figure 1. Factors that determine land marginality (adapted from Kang et al., 2013b)

Physical land variables include depth above hard rock, flooding, slope, etc. Soil physical parameters on the other hand focus on soil properties such as texture classes (sand, silt, clay content), pH (acidity/ alkalinity), moisture, drainage, etc. These two categories are the most widely used to identify land marginality (European Union, 2013; Fu et al., 2014; Gopalakrishnan et al., 2011; Lu et al., 2012; Milbrandt & Overend, 2009; Mustafa et al., 2011; Zhuang et al., 2011). Variables relating to environmental and ecological aspects, such as biodiversity and soil organic carbon trend are more difficult to quantify and are often applied as restrictions for specific land uses (Cowie et al., 2006; Dale et al., 2010; Hart et al., 2013; Niu & Duiker, 2006). Social and economic criteria to factor in the efficiency of cultivating bioenergy plants, such as breakeven price or yield, market demand and accessibility are also evaluated (Caldas et al., 2014; Skevas et al., 2014).

In the context of SEEMLA, marginal land mainly includes sites that exhibit poor site conditions due to low soil fertility and clear economic inefficiencies with regard to agricultural usability, as described in deliverable D2.1. This definition excludes sites with potentially high productivity which was set aside or temporarily abandoned due to certain socio-economic reasons. In addition, badlands with naturally extreme low soil fertility as well as most parts of brownfields or anthropogenic wastelands are not within the focus of SEEMLA. The infertility of the latter sites is regarded as a clear obstacle for a profitable biomass production.

Also, according to deliverable 3.2: “Report on regional policies for the use of biomass from MagLs and strategies for pilot cases”, in order to plan the use of such sites on a larger scale, an assessment of potential MagL is needed, based on (1) soil properties and soil fertility assessments and (2) on a spatially explicit selection of suitable sites with an adapted GIS approach.

The identification of marginal lands, as defined above, requires examination of a wide spectrum of parameters related to the factors that define marginality. Deliverable 2.3: “Report on MagL concepts, debate and indicators” has provided a thorough literature review on this issue and has proposed specific indicators for the SEEMLA project. These indicators express major land characteristics contributing to land marginality and provide the basis for the development of the specialized tools (included in WP6) to identify MagLs and assess their availability in Europe. The SEEMLA algorithm however is not limited to biophysical soil properties but also incorporates environ-ecological and economic factors to provide an integrated approach on land marginality assessment.

2 Indicators for the identification of MagLs

Due to the diverse definitions of marginal lands, the indicators used to identify them in the past differ significantly as do the methodologies applied to combine them. The indicators in the specific context of SEEMLA should efficiently translate the definition of MagLs into tools that could support decision making.

The first step to identify these indicators included literature review and listing of marginality criteria used in other projects, as well as other parameters specific to the SEEMLA approach.

The approach of D2.3 incorporates land characterization by introducing the Soil Quality Rating system (Mueller et al., 2007), as the basis for an efficient integration of land characteristics into marginality categories. The Soil Quality Rating Index (SQR) is adopted by SEEMLA to assess soil fertility and resulting yield potentials. This method was developed primarily for agricultural crop yield potentials related to soil fertility, using empirically based scores ranging from 0 (no farming possible) to 100 (prime farmland):

Very poor	Poor	Moderate	Good	Very good
<20	20 - 40	40 - 60	60 - 80	> 80

Sites with calculated SQR scores below 40 indicate MagLs within the SEEMLA context, representing poor (SQR 20 – 40) or very poor soil conditions (SQR< 20). These thresholds may be reviewed during the project duration, based on the results from the pilot cases (WP5) and socio-economic assessment (WP4).

Also, deliverable 2.3 provided a list of indicators, adapted from the EU Regulation (1305) 2013 on thresholds and marginality for conventional agriculture in Europe. They are based on climate (temperature, aridity), soil (drainage, texture, rooting depth, chemical properties) and terrain (slope) criteria. Ten different sub-categories of MagLs have been proposed by D2.3, based on the restricting factors for growing conventional agricultural crops (Table 1).

Table 1. Sub-categories and criteria of MagL modified and adapted from Regulation EU (1305)2013 (European Union, 2013; Joint Research Centre, 2014) by IBC & SB

Sub-categories of MagL	Criteria
1.Shallow rooting depth	depth (cm) from soil surface to coherent hard rock or hardpan
2.Stony texture	high volume percentage of stones
3.Sandy texture	high sand content
4.Clay texture	high clay content
5.Saline	high content of salts
6.Sodic	high exchangeable sodium content (ESP)
7.Acidic	low pH

Sub-categories of MagL	Criteria
8.Overwet	low underground water table; gleyic color pattern
9.Steep slope	steep slope
10. Contaminated	high content of nitrate in groundwater

Moreover, additional criteria and indicators were reviewed to compile a complete catalogue of climate, physical, biological, environmental, ecological, as well as social and economic parameters to provide a comprehensive assessment of land marginality. The overall potential indicators for the SEEMLA approach identified are listed in Table 2.

Table 2. SEEMLA approach indicators for the identification of MagLs (DUTH)

No	Category	Criterion	Examples of potential SEEMLA indicators	References
1	Climate	Precipitation	Annual precipitation Precipitation of Driest Quarter	Biggs (2007), Nelson et al. (1997)
2		Temperature	Lowest winter temperature Monthly temperatures (mean, min & max)	Joint Research Centre (2014)
3		Aridity	UNEP aridity index (AI) Hydrothermal coefficient (HTC)	Joint Research Centre (2014)
4	Land use/ cover	Land cover	Marginal agricultural land, Riparian buffer strips, Roadway buffer strips Exclude certain land uses (lakes, rivers, settlements, irrigated lands, etc)	Gopalakrishnan et al. (2011)
5	Ecological – environmental issues	Critical habitats for protected species	Exclude critical habitats for protected species	Hart et al. (2013)
6		Priority habitats	Exclude priority habitats	Allen et al. (2014)
7		Protected areas	Exclude absolute nature reserves, areas of outstanding natural beauty, etc	Hart et al. (2013)
8		Soil organic carbon (SOC)	Decreasing trend as a marginality factor. High SOC may face depletion in biomass production systems	Kang et al. (2013b) Cowie et al. (2006)
9	Socio-economic	Area & shape of the land parcel	Minimum area for economically efficient cultivation - closer to rectangular shape	Allen et al. (2014)
10		Social data	Main economic activity Population dynamics (age & size)	Caldas et al. (2014)
11		Proximity to processing facility	Distance classes based on proximity to the next supply chain link	Allen et al. (2014)

No	Category	Criterion	Examples of potential SEEMLA indicators	References
12	Socio-economic	Breakeven price or yield	Production level to identify economically marginal lands, unfavourable output/input ratios	Kang et al. (2013b), Nelson et al. (1997)
13		Economic efficiency indicator	Absence of markets, small holdings, restrictive land tenure, poor infrastructure	Nelson et al. (1997)
14		Accessibility	Proximity to main transport networks	Allen et al. (2014), Nelson et al. (1997)
15	Terrain	Steep slope	Slope limiting the use of mechanical means for cultivation	Gopalakrishnan et al. (2011), Joint Research Centre (2014), Nelson et al. (1997)
16	Soil	Soil texture classes (FAO)	Unfavorable soil substrate: Light, sandy soils and heavy, clayey soils	Joint Research Centre, (2014), Mueller et al. (2007)
17		Soil depth	Shallow Rooting Depth	Joint Research Centre (2014), Liu et al.(2011), Mueller et al. (2007), Nelson et al. (1997)
18		Limited drainage - Wetness and ponding	Limited drainage - Wetness and ponding	Gopalakrishnan et al. (2011), Joint Research Centre, (2014), Mueller et al. (2007), Nelson et al. (1997)
19		Soil pH	Acidification, alkalization	Joint Research Centre, (2014), Kang et al.(2013b), Mueller et al. (2007)
20		Soil contamination	Heavy metals, nitrates	Gopalakrishnan et al. (2011)
21		Soil sodicity	High exchangeable sodium content	Joint Research Centre (2014)
22		Soil salinity	Strong to extreme salinization	Joint Research Centre (2014), Kang et al.(2013b), Liu et al.(2011), Mueller et al. (2007), Nelson et al. (1997)
23		Soil thermal regime	Duration of frost free period	Mueller et al. (2007)
24		Soil compaction	Subsoil structure	Mueller et al. (2007)

No	Category	Criterion	Examples of potential SEEMLA indicators	References
25	Soil	Rock at the surface	Coverage classes for stones and boulder at the surface	Joint Research Centre (2014)
26		Soil productivity (Land types)	Land classification for specific uses (e.g. agriculture, forestry) based on soil biophysical constraints	Nakos (1991), Nelson et al. (1997)
27		Soil humidity index	Profile available water, drought risk	Cai et al. (2011), Kihoro et al. (2013) Lewis & Kelly (2014), Montgomery et al. (2016), Mueller et al. (2007)
28		Soil cation exchange capacity	Low CEC values	Joint Research Centre (2014)
29		Soil erosion	K factor	Gopalakrishnan et al. (2011), Zolekar & Bhagat (2015)
30		Workability	Soil properties constraining soil management (soil depth, rock outcrop, stoniness, gravel/ concretions and hardpans)	Fischer et al.(2008), IIASA/FAO (2012)

In order to incorporate these indicators into the SEEMLA GIS tool corresponding, spatial datasets are required. More than 100 datasets were reviewed as potential SEEMLA indicators, a complete list of which is provided in Annex I. The coverage of the 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. The potential use of each dataset is marked in the table of Annex I (SQR, elimination criteria for MagL identification, bioenergy crops and validation of the results of the SEEMLA tools).

These datasets need to be assessed in terms of accuracy, coverage (national, European, global), relevance, availability, etc. in order to determine which are best suited for the SEEMLA approach. Issues of uncertainty and error depending on the input data will be addressed by applying uncertainty and sensitivity analysis. Also, it is important to make sure that the latest version is being used or if any new datasets are available. The list of indicators – datasets will be finalized in WP6, during the development of the ArcGIS application.

Finally, economic data is required regarding the establishment, treatment and harvesting costs for each crop, as well as the overall revenue and rotation period. This information will be provided by the outputs of Work Packages 4 and 5 and will be incorporated in the tools during WP6.

It is important to keep in mind that marginality may be temporary in some cases, especially when it is related to economic indicators or physical parameters that can be improved with proper treatment (Figure 2). Therefore, it is necessary to build dynamic tools to identify marginal lands and assess their state whenever new data is available.

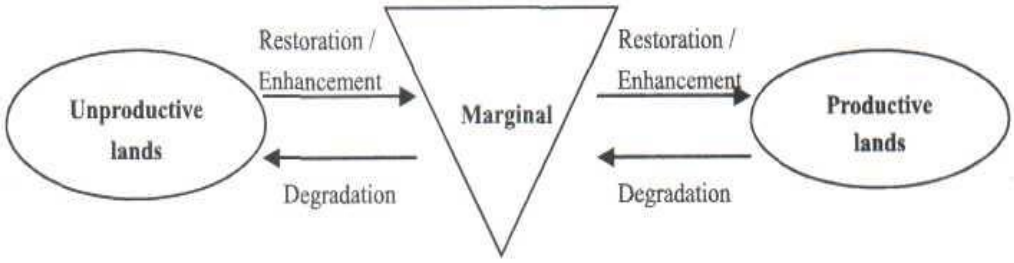

Figure 2. A transitional state of land uses – marginal lands (Kang et al., 2013a)

The information provided above is the basis for the development of the SEEMLA tools aimed at the identification of MagLs and the determination of the marginality sub-category they fall under. Still, thresholds will need to be defined for each indicator in order to eliminate lands that are either not marginal or cannot be used for growing bioenergy plants, thus locating the lands within the SEEMLA scope based on the algorithm developed by the project consortium.

The web-based and GIS applications form an integrated toolset for the identification of marginal lands. The first application is addressed to stakeholders that require site specific information regarding land marginality within the SEEMLA context. It will be an easy to use application that requires only a web browser. The GIS application on the other hand deals with datasets at European level and will require specialized software and training in order to be used. However, its output raster datasets will be accessible to all, either through the web-based application or as downloadable data available through the SEEMLA project website and the European Environment Information and Observation Network (EIONET) of the European Environment Agency (EEA).

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3 Bioenergy crops

Identifying marginal lands is not the only objective of the SEEMLA tools. Once marginal lands are located, the most efficient bioenergy crops for those specific lands need to be determined. This task requires knowledge on the growth requirements of each species. To that end, deliverable 2.2 reviewed 18 non demanding woody and perennial crops that can provide stable high yields of high-energy-capacity biomass on marginal lands. Deliverable 2.3 provided specific climate and soil requirements for 6 of these plants (Table 3).

Table 3. Land marginality as a combination of soil and climate handicaps (IBC&SB)

Sub - categories of MagL	Mediterranean	Maritime		
	P[1]=300-600 mm T[2]=14-17°C HTC[3]=0.3-0.5	P=1000-700 mm; T=10-15°C HTC=1.5-2	P=700-600 mm; T=8-10°C HTC=0.8-1.5	P=600-300 mm; T=2-8°C HTC=0.8-0.5
Shallow rooting	Pine, Switchgrass	Pine, Switchgrass	Pine, Switchgrass	Pine, Switchgrass
Stony texture	Black locust, Pine	Willow, Poplar, Black locust, Pine	Willow, Poplar, Black locust, Pine	Black locust, Pine
Sandy texture	Black locust, Pine, Switchgrass	Willow, Poplar, Black locust, Pine, Miscanthus, Switchgrass	Willow, Poplar, Black locust, Pine, Miscanthus, Switchgrass	Black locust, Pine, Switchgrass
Clay texture	Black locust, Pine, Switchgrass	Black locust, Pine, Miscanthus, Switchgrass	Poplar, Black locust, Pine, Miscanthus, Switchgrass	Black locust, Pine, Switchgrass
Saline	Black locust, Pine, Switchgrass	Poplar, Black locust, Pine, Miscanthus, Switchgrass	Poplar, Black locust, Pine, Miscanthus, Switchgrass	Black locust, Pine, Switchgrass
Sodic	Black locust, Pine, Switchgrass	Black locust, Pine, Miscanthus, Switchgrass	Black locust, Pine, Miscanthus, Switchgrass	Black locust, Pine, Switchgrass
Acidic	Black locust, Pine, Switchgrass	Willow, Poplar, Black locust, Pine, Switchgrass	Willow, Poplar, Black locust, Pine, Switchgrass	Black locust, Pine, Switchgrass
Overwet	Pine, Switchgrass	Willow, Poplar, Pine, Miscanthus, Switchgrass	Willow, Poplar, Pine, Miscanthus, Switchgrass	Pine, Switchgrass
Steep slope	Black locust, Pine, Switchgrass	Poplar, Black locust, Pine, Miscanthus, Switchgrass	Black locust, Pine, Miscanthus, Switchgrass	Black locust, Pine, Switchgrass
Contaminated	Black locust, Pine, Switchgrass	Willow, Poplar, Black locust, Pine, Miscanthus, Switchgrass	Willow, Poplar, Black locust, Pine, Miscanthus, Switchgrass	Black locust, Pine, Switchgrass

However, more detailed information is required for the development of the SEEMLA tools to determine land suitability for the specific crops and also incorporate special features that would support the decision making process, such as frost resistance or suitability for restoration of disturbed sites.

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[1] P – average (mean) annual precipitation (mm)

[2] T – average (mean) annual temperature (°C)

[3] HTC (hydrothermal coefficient) = P/0,1∑t higher 10°C (P - total precipitation for vegetation period)

Based on the information provided by IBC & SB in WP2, DUTH created a matrix including all 18 proposed bioenergy crops supplemented their growth requirements with further literature review and determined thresholds necessary for the incorporation of the crops in the decision-making algorithm. The complete list is provided in Annex IIa, whereas the data concerning species only used in the SEEMLA pilot cases are shown in Table 4.

Table 4. Demands of SEEMLA bioenergy crops (DUTH)

Common name		Black locust	Black pine	Basket willow	Poplar	Miscanthus giganteus	Switchgrass
Scientific name		*Robinia pseudoacacia* L.	*Pinus nigra*	*Salix viminalis L.*	*Populus sp. L*	*Miscanthus × giganteus*	*Panicum virgatum* L.
Type of plant		Woody	Woody	Woody	Woody	Herbaceous	Herbaceous
Drought resistance		X	X	-	-	-	X
Annual rainfall (min - max)		600 - 2 000 mm	350 - 2 200 mm	550 - 1 100 mm	550 - 1 000 mm	400 - 700 mm	380 - 760 mm
Optimum Annual rainfall (min - max)		1 020 - 1 830 mm	800 - 1 500 mm	600 - 1 000 mm	700 mm	700 - 800 mm	400 mm
Lowest winter temperature		- 12°C	-30°C		- 29°C	- 23°C	- 22°C
Average day temperatures (min / max)		-4 / 35°C	-	-	-5 / 31°C	25 / 32°C	10 / 29°C
Optimum Average day temperatures (min / max)		10 / 18°C		20°C	9 / 17°C	8.5°C	10 / 18°C
Frost resistance		-	X	X	X	X	X
Altitudinal range (min - max)		0 - 1040 m	800 - 1500 m	0 - 570 m	0 - 1200 m	700 - 1000 m	0 - 700 m
Suitable for restoration of disturbed sites		X	X	X	X		X
Soil Texture	Sandy	X	X	X		X	X
	Highland acid moors	X					
	Limestone - rocky	X	X			X	X
	Loam	X	X	X			X
	Heavy clay	X	X	X		X	
	Peat						
Soil pH (min - max)		4.5 - 8.2	4 - 8	5 - 7.5	4.5 - 7.5	5.5 - 7.5	5 - 7
Soil moisture		well-drained	dry	well-drained sandy wet loamy soils	wet	moist, well-drained	moderately to well-drained
Land use							Excellent plant to use in riparian buffer strips or on other sensitive lands

The requirements of the plants include climate (temperature & precipitation) and biophysical (elevation, soil texture, pH and moisture) parameters. Moreover, economic data regarding the average yield and rotation period of each bioenergy crop are required in order to determine their economic efficiency. Information regarding these economic parameters, as well energy output and propagation for all species is provided in Annex IIb. The data incorporated into the SEEMLA toolset will be modified/supplemented based on input from all partners and the results of WP4 and WP5 as well.

The spatial datasets of Annex I will be used to determine the suitable crops for each land parcel. However, not all required data are available for Ukraine or for all EU countries (missing data for Croatia, Cyprus, Latvia & Malta). In these cases, bioenergy crops will be selected based on the information on hand.

4 SEEMLA algorithm

A first approach towards the SEEMLA algorithm for the identification of marginal lands and suitable bioenergy crops was developed in deliverable 2.3 by IBC & SB. The algorithm was further elaborated by DUTH in order to establish a detailed development plan for the SEEMLA toolset (Figure 3).

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.

Land marginality is assessed taking into account the individual effect of each variable that constrains plant growth. A land is considered marginal if crop production is limited by at least one factor, such as soil or climate (Biggs, 2007; Kang et al., 2013a; Milbrandt & Overend, 2009).Therefore, a land parcel is considered marginal if any of the constraints of Figure 3 applies.

However, within the SEEMLA approach, soil biophysical criteria are used for the identification of marginal lands, either individually or, more importantly, combined with ecological criteria to reflect soil suitability for cropping. The Muencheberg Soil Quality Rating system (SQR) falls into the latter category and has been selected as the basic marginality indicator for SEEMLA. This methodology combines the aforementioned biophysical, and also chemical, soil criteria.

The 1st level of analysis includes the calculation of the SQR score and the identification of marginal lands as those with scores below 40. The SQR Assessment scheme, as applied by BTU CS for the pilot cases (see D5.2), consists of three combination rules[4]:

Combination Rule 1:

Determination of Sum of SQR Basic Soil Indicators (Total basic score)

Input data: scores of basic indicators 1-8

BI1: Soil texture up to 80 cm depth

BI2: Depth (cm) of the humic A horizon

BI3: Topsoil structure

BI4: Packing density of subsoil

BI5: Effective rooting depth

BI6: Available field capacity within rooting depth

BI7: Average deepest groundwater level

BI8: Slope

[4] This is a simplified approach, focusing only on the final calculations. More calculations are required for each basic and hazard indicator, according to the detailed SQR assessment scheme.

ΣBI1-8 = BI1 * 3 + BI2 * 1 + BI3 * 1 + BI4 * 1 + BI5 * 3 + BI6 * 3 + BI7 * 3 + BI8 * 2

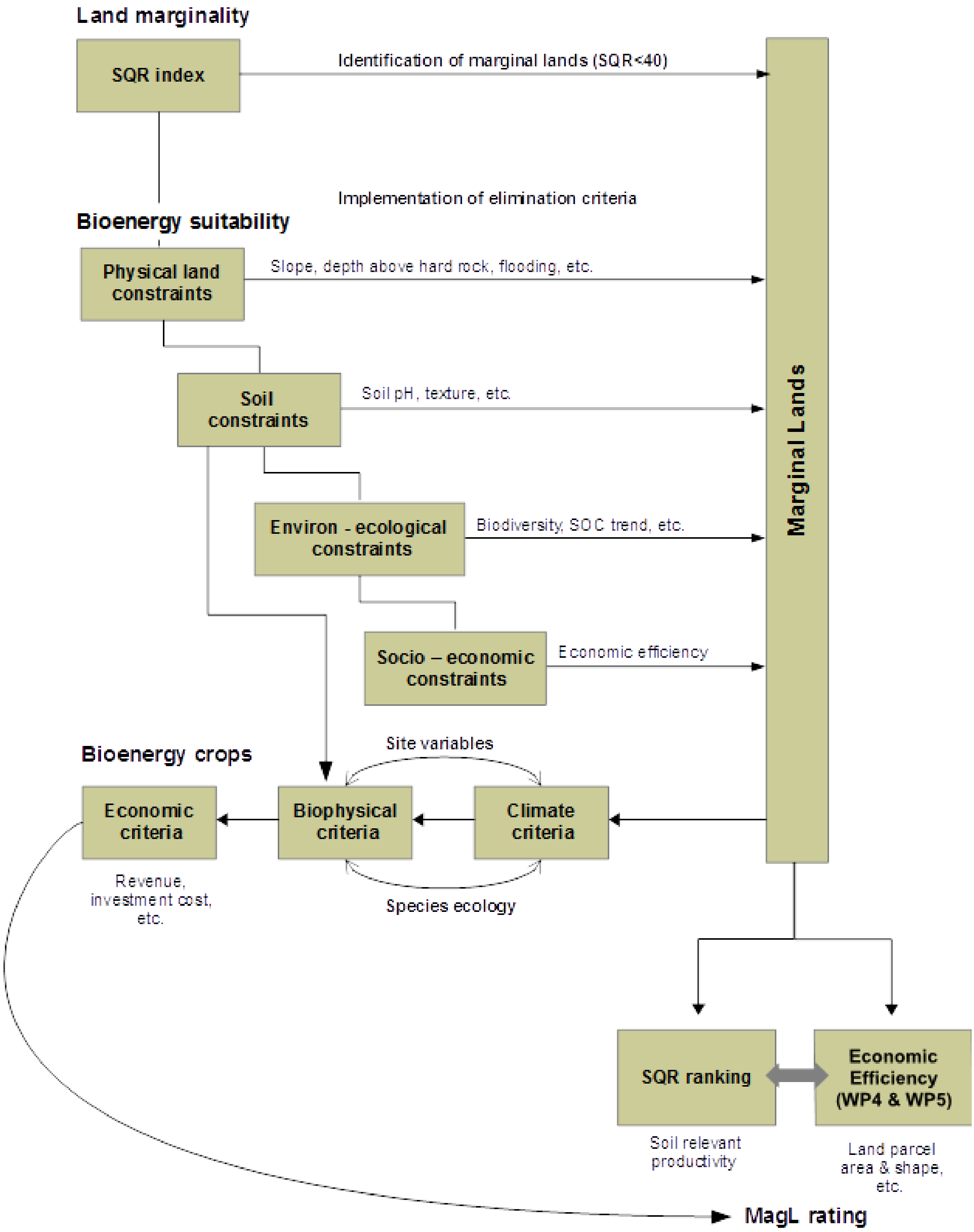

Figure 3. SEEMLA algorithm for the development of tools (DUTH)

Combination Rule 2:
Determination of SQR Multiplier Value (Lowest multiplier)

Input data: multipliers of hazard indicators
HI1. Contamination
HI2. Salinisation
HI3. Sodification
HI4. Acidification (pH-value of A-horizon)
HI5. Low total nutrient status
HI6. Soil depth above hard rock
HI7. Drought - Effective water balance (De Martonne Aridity Index)
HI8. Flooding and extreme waterlogging
HI9. Steep slope
HI10. Rock at the surface
HI11. High percentage of coarse soil texture fragments
HI12. Unsuitable soil thermal regime
HI13. Miscellaneous hazards
The indicator with the lowest multiplier is selected and used as the most important hazard indicator for the final calculation (**HIfinal**). Indicators HI4, HI6, HI7 & HI11 are considered the most important and will be taken into account for the calculation of the SQR index. The remaining indicators will be incorporated into the analysis at a later stage, provided that spatial datasets are available.

Combination Rule 3:
Determination of final SQR Value (Final rating score)
Input data: sum of basic indicators & multiplier of most important hazard indicator

SQR = ΣBI1-8 * HIfinal

The 2nd level of analysis includes the exclusion of marginal lands that are unsuitable for the cultivation of bioenergy crops. In order to locate MagL that can be used for growing energy crops specific thresholds are required for each indicator. The adaptation of the EU Regulation (1305) 2013 by the IBC&SB[5] has provided a value range that corresponds to each SEEMLA MagL sub-category. These minimum and maximum values have been included in Table 5. Also, based on these ranges, elimination thresholds have been determined and additional variables have been included to identify land that cannot be used for bioenergy cropping, incorporating the SQR scoring for hazard indicators.

[5] SEEMLA deliverable 2.3: "Report on MagL concepts, debate and indicators"

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Table 5. Indicators and threshold values[6] to exclude unsuitable MagL for growing energy crops

Indicators	Sub-categories of MagL (D2.3)	Criteria	Min	Max	Elimination threshold[7]
1) Rooting depth	1. Shallow rooting depth	low soil depth with down hard pan	25 cm	35 cm	<25 cm
2) Soil stone content	2. Stony texture	high volume percentage of stones	10%	20%	>20%
3) Soil sand content	3. Sandy texture	high sand percentage	40%	60%	> 60%
4) Soil clay content	4. Clayey texture	high clay percentage	-	60%	> 60%
5) Salts content	5. Saline	high content of salts	3.2	16	> 16 dS/m
6) Exchangeable sodium percentage (ESP)	6. Sodic	high exchangeable sodium content	4.8	8	> 8 ESP
7) Electric Conductivity (EC)	6. Sodic	strong to extreme salinization	8	16	>16
8) Soil pH	7. Acidic	pH level	4	5.5	< 4
9) Ground water level	8. Overwet	low level of underground water (6 months)	80 cm	-	-
10) Depth to a gleyic horizon	8. Overwet	gleyic color pattern	40 cm	-	-
11) Contamination of underground water by nitrates	9. Contaminated	content of nitrate in groundwater	10 mg L^{-1}	-	-
12) Steep slope	10. Steep slope	ease at which crops can be grown and harvested	-	15%	>30%
13) Soil organic carbon	-	unfavourable soil texture			≥30% in 40 cm
14) Contamination	-	land contaminated with heavy metals or organic contaminants	Boolean ("true" values are excluded)		
15) Erosion risk	-	high erosion risk			
16) Land use	-	lakes, rivers, irrigated croplands, settlements, etc.	Boolean ("true" values are excluded)		

[6] Based on D2.3 (Indicators No 1-6, 8-11), SQR (No 7, 12,18), EU regulation 1305/2013 (No13)

[7] The minimum and maximum values, as well as the elimination thresholds for each indicator will be reviewed over the project duration and finalized in deliverables 6.6 and 6.7.

Indicators	Sub-categories of MagL (D2.3)	Criteria	Min	Max	Elimination threshold[7]
17) Nature protection areas	-	Absolute nature reserve, area of outstanding natural beauty, etc	Boolean ("true" values are excluded)		
18) Aridity	-	De Martonne Aridity Index			< 5 (extremely arid)
19) Economic efficiency		proximity to processing facility			>50 km[8]

The additional variables only represent elimination criteria that may either be numerical (threshold values) or Boolean (true/ false), but do not necessarily form marginality sub-categories. Other criteria that are not influenced by the crop, such as proximity to processing facilities are also evaluated in this phase.

Elimination criteria are used to exclude areas that are not suitable for the cultivation of bioenergy plants. These criteria are used to eliminate land parcels from the datasets that will be used in the analysis and are not necessarily related to the marginality of the land (i.e. land use).

MagL indicators include qualitative or quantitative variables that determine the source of land marginality. Their thresholds are therefore used to create subsets of marginal lands based on each indicator according to deliverable D2.3, which identifies 10 marginality sub-categories (Table 5). The application of the elimination criteria and MagL indicators results in the identification of MagLs available for bioenergy cropping within the SEEMLA context.

The 3rd analysis level of the algorithm involves the selection of bioenergy crops that are suitable for each MagL. This process cross-references the site variables with the ecological demands of the plant species in order to determine which ones could be cultivated in each land category. The parameters taken into account are presented in Table 6. Economic criteria are then incorporated into the analysis to estimate the efficiency of each of the suitable crops (establishment costs, rotation period, fluctuation of prices, market demand, etc.).

Table 6. Crop suitability parameters

Parameters	Value range
Annual rainfall	Must be in range (min – max)
Drought risk	Low, medium, high
Frost risk	Low, medium, high
Altitudinal range	Must be in range (min – max)

[8] Based on the results of the BIOEUPARKS project: Exploiting the potentialities of solid biomasses in EU Parks (2013 – 2016)

Parameters	Value range
Disturbed site[9]	Boolean (yes/no values)
Soil	Sand, Loam, Heavy clay, Highland acid moors, Peat Limestone – rocky parent material
Soil pH	Must be in range (min – max)
Soil moisture	Dry, well-drained, moist, wet, flooded

The last phase of the algorithm involves the rating of MagLs. This approach takes into account biological and ecological factors as well as the viability of the investment. For example, if a small land parcel receives an SQR score slightly higher than a larger parcel, and there are no other restrictions, this does not necessarily mean that the first one should be preferred for the establishment of bioenergy crops, solely on the basis of SQR value. The economic efficiency of the investment should be considered as well. The purpose of this last procedure is, therefore, to rate MagLs based on their potential for biomass production, taking into account their soil quality, economic efficiency and any other factor that affects decision-making.

Policies for marginal land use should take into account multiple objectives. As described by FNR (see D3.2), on one hand aspects of environmental protection are receiving a lot of attention, while on the other hand the economic, but still sustainable use of MagLs for the production of biomass for bioenergy is of great interest.

The SEEMLA algorithm will be further developed utilizing the results of WP3[10], WP4, WP5 and WP6, in order to fine-tune the tools to better represent the SEEMLA approach.

[9] Mechanically disturbed (i.e. mines) or contaminated sites

[10] Deliverables D3.1, D3.2 & especially D3.3 *"Catalogue of proposed policies on regional and EU levels"*

5 Web-based application

5.1 Aim of the web-based application

The web-based application which will be developed by the SEEMLA project aims to assist users that require advisory information for MagL exploitation, based on the results of the project.

The web app will combine a user interface comprising the criteria and indicators described in the SEEMLA algorithm and spatial datasets deriving from the SEEMLA ArcGIS model developed in WP6. The application will analyze all available data to determine whether a specific land parcel (or unit) is considered marginal within the SEEMLA context, which sub-categories of marginality it falls under and which crops it can efficiently sustain.

Web – based applications offer a range of advantages. Since they use a website as platform, no special software is required to view the data, just a web browser. A large number of users can easily access the data, without any previous training or experience. These two features are very important due to the fact that the SEEMLA web app will incorporate spatial datasets (outputs of the GIS application) that would not otherwise be accessible to the general public. Special software is required to develop the application but the end user needs only basic computer skills to obtain any information. Last, the platform can be easily updated, providing immediate access to the latest version for all clients.

5.2 Methodology for the development of the SEEMLA web-based application

In order to meet the needs of the SEEMLA web-based application the following functionalities are required:

- Management of organized data (Databases)
- Output production, based on the choices that the user makes
- Personalization of the outputs and keeping records for every authorized user
- A Graphic User Interface (GUI) that will assist the user in determining some of the parameters of the calculation algorithm, in case that the specific values are unknown.

In order to organize and develop such an application, a framework with application development capabilities for dynamic web pages is required, as well as a Web-Database Management System.

The requirements of the application are met by free open source software for the language and programming platform, as well as the web-Database management system. Thus, the web application will be developed using the PHP programming language, through the "*Laravel*" PHP web framework, whereas the web Database will be managed with MySQL Database Management System (DBMS).

The web application will be developed in 3 stages.

During the 1st stage, efforts will be made to cover the functional needs of the project with a simple interface provided by the *Laravel* framework.

The 2nd stage will include the procedures to determine the SQR score at a given point or area with the help of geospatial data, using the Google Maps API to view KML Map Layers.

The 3rd stage will deal with improving the user Interface with the use of a Javascript User Interface Framework package, in order to make the system more user-friendly and functional.

Stage 1: System functionality

This is the development stage of the application, which includes setting up the system (databases, forms, etc.) and a basic Graphic User Interface (GUI). Initially, only authorized users from the project team will be granted access to the application (1-2 users from each partner of the SEEMLA project). The registration functionality for guest users will be disabled for security reasons at this point. At the end of this stage, users will be able to use the platform for evaluating specific areas of interest, by providing the required information for each of the three (3) forms of the application (Figure 4).

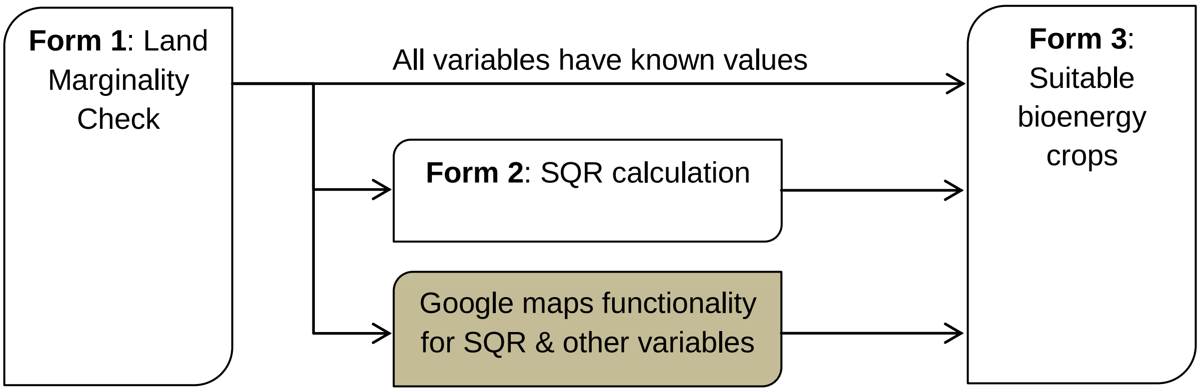

Figure 4. Overview of the web – based application forms - GUI

The process starts with the presentation of a table containing the queries that the user has performed in the past (query history), and also the capability to start a new query for marginal lands. When selecting the creation of a new query *Form 1. "Land Marginality Check"* opens and the user is required to fill in an indicative name for the parcel in question and then values for the indicators described in the SEEMLA algorithm for MagL identification (Table 5). Values within the marginality range will be highlighted.

The platform will also provide a separate form for the calculation of the SQR index for a specific land parcel (*Form 2. SQR calculation*). This functionality is provided due to the fact that the SQR is a basic marginality indicator and the only one that involves equations, using predefined scores and weights. In order to use this form, field measurements and soil sampling is required, as described in Mueller et al. (2007) and applied by BTU CS for the pilot cases of the SEEMLA project. This approach provides the most detailed and accurate assessment of SQR, since the user has to provide values for each of its input parameters[11]:

[11] For more information see deliverable 5.2 (BTU CS) and Mueller et al. (2007)

Soil physical parameters

- Soil texture classes
- Sand content of subsoil [%]
- Content of coarse particles [%]
- Bulk density A-horizon [g/cm³]
- Bulk density of subsoil [g/cm³]
- Topsoil soil structure (can be estimated from soil texture and soil types)
- Depth above hard rock [cm]

Soil chemical parameters

- Depth (cm) of the humic A horizon]
- pH - values of A-horizon
- Average deepest groundwater level below surface [m]

Additional site parameters

- Slope of the site [%]
- Effective water balance during the main vegetation period

The form returns the SQR value which can then be inserted into Form 1. In case the result of Form 1 is positive (the land is marginal), the user can carry on to find out which bioenergy crops are suitable for the specific MagL, through *Form 3 "Suitable bioenergy crops"*. This form will require additional data in order to determine the bioenergy crops. All fields need to be filled in for this form to provide correct results - contrary to Form 1 where providing just one field value could suffice. The web application will incorporate species requirements that have already been reviewed by the SEEMLA project. However, a function will be available for authorized users to add the demands of more bioenergy crops, in order to assess their suitability for MagLs. Guest users will not have this option for security reasons, but would be able to contact the administrator of the application to request additions.

Economic criteria will also be included in the application, based on the results of WP4 and WP5, to identify economically marginal lands (Form 1) and to evaluate the economic efficiency of each crop (Form 3).

Stage 2: Incorporation of Google Maps functionality

The web application will also incorporate a Google Maps API (Application Programming Interface). This functionality will allow users to view and acquire information from predetermined spatial datasets incorporated into the system. These datasets will either be outputs of the SEEMLA GIS application (i.e. SQR scores, MagL sub-category, etc.) or public-use data.

The user will be able to get the value for a specific indicator based on the location he has provided. Therefore, the only inputs required are the coordinates of the land parcel. This functionality will be supported by the Google Map basemap (with satellite coverage), which enables the user to view raster datasets as KML Map Layers. The user will then be able to click on the map and get the value of the specific point for the selected indicator, which can then be filled in the first form ("Land Marginality Check").

Google Maps interoperability will be incorporated into all 3 Forms, to allow the user to draw values for the specific parameters from spatial datasets. The coverage provided will depend on the availability of the specific data for all EU countries. Due to the fact that the extent of all available datasets is not global there may be cases that e.g. the SQR score could not be calculated for some areas. The user is then restricted to use Form 2 to calculate it. If the SQR score for the parcel is known (i.e. arable lands of Germany), the user can just type in the value in the corresponding field, as shown in Figure 4 and skip Form 2 and the Google Maps API altogether.

It should be noted that this approach is subject to error propagation or even amplification due to the fact that it utilizes the outputs of spatial modelling operations (Arbia et al., 1998; Crosetto et al., 2000; Feizizadeh & Blaschke, 2014; Heuvelink et al., 1989; Ligmann-Zielinska & Jankowski, 2014; Saltelli et al., 2010). A relative warning note will be prompted to the user.

Stage 3: Functionality improvement

The 3rd and last stage of the application development involves the use of a Javascript User Interface Framework, to improve the functionality of the forms, and provide a more user-friendly and efficient environment for the users.

The functionality of the fields in the form will incorporate validation rules to guide and prevent the user (through Javascript) from providing false or out of range values in the corresponding form fields. At the same time, the GUI will be refined with the use of improved styling graphics for the objects of the application.

Application development

The application will be developed locally, in PHP 5.5.12 and MySQL 5.6.17 environments with the use of *Laravel 5.2*. The versions that will be used are the last "Stable" ones (and not the latest ones) in order to ensure the compatibility of the final version of the application with the Server environment that will host it.

6 GIS application

6.1 Aim of the GIS model

The SEEMLA GIS toolset comprises geoprocessing models to automate and document the data management and spatial analysis for the identification and assessment of marginal lands in Europe.

The tool aims to answer the following questions:

- Which land is marginal
- What makes the land marginal (marginality sub-categories determined in D2.3)
- Which land is more efficient for growing bioenergy plants - MagL rating
- Which crop is best suited for it

The toolset will be developed in Task 6.1 and finalized in Task 6.3, in order to incorporate the environmental and socioeconomic assessment (WP4) of pilot cases (WP5), which will contribute to the evaluation of alternative exploitation scenarios (WP6). Also, WP3 outputs regarding regulatory and legal restrictions and constraints posed by national or EU policies applied will be taken into account.

The application will be developed as a customized toolbox for ESRI ArcGIS, which will be installed locally. No internet connection would be required to use it, as opposed to the web application that will be available only online. Also, the application will require specialized software (ESRI ArcGIS), as well as users with some experience in GIS. The users will have to determine the input datasets, either those used in SEEMLA or other available raster files. They will also be able to modify the tools based on their specific needs, by adding or excluding criteria. Before using the tools, the user will be advised to review the spatial datasets (national, regional, etc.) and various bioenergy crops in order to use the most recent and accurate data available.

The GIS application is addressed to specific users, with experience in the specific field. The outputs of this application however will be available to the public either through the web application or as thematic maps.

6.2 Overview of GIS model used for land suitability

Multiple-Criteria Decision Analysis (MCDA) provides a rich collection of techniques and procedures for structuring decision problems, and designing, evaluating and prioritizing alternative decisions (Malczewski, 2006).

A Geographic Information System (GIS) is a valuable decision support tool for any problem involving spatial datasets. Therefore, land suitability analysis for various purposes is nowadays interconnected with GIS. As far as mapping the availability of marginal land for bioenergy crops is concerned, there has been an increase in published work that uses GIS since 1993 (Lewis & Kelly, 2014). In the last decades various methods have been applied for land suitability assessment that may be applicable for assessing marginal land availability within the SEEMLA context (Table 6).

Table 7. Literature review of GIS methods applied for land suitability assessment

Author	Date	GIS method	Purpose	Scale
Zoccali et al.	2017	Fuzzy logic (Linear Fuzzy Membership Function)	Assessment of land suitability for beekeeping	Regional (Calabria region, Italy)
Montgomery et al.	2016	Logic Scoring of Preference	Identification of land capability and suitability for agricultural use	Regional (Boulder County, Colorado USA)
Zabihi et al.	2015	Analytical network process	Achievement of optimum crop yield and decrease the loss of citrus production	Regional (Ramsar district)
Zhang et al.	2015	Fuzzy logic and Analytical Hierarchy Process (AHP)	Assessment of land suitability for tobacco production	Regional (Shandong province, China)
Zolekar & Bhagat	2015	Multi Criteria Evaluation (MCE) and AHP	Analysis of land suitability for agriculture	Local (stream zone in Mula and Pravara basins in Western Ghats, Maharashtra India)
Kihoro, Bosco, & Murage	2013	Multi criteria evaluation with Weighted Linear Combination (WLC)	Investigation of the suitability for rice growing sites	Regional (Mwea region, Kenya)
Akinci, Özalp, & Turgut	2013	Analytical Hierarchy Process (AHP)	Determination of suitable areas for agriculture	Local (Yusufeli district of Artvin city (Turkey)
Lu et al.	2012	Overlay analysis	Chinese Pistache (Pistacia chinensis) potential mapping on **marginal lands**	National (China)
Feizizadeh & Blaschke	2012	MCE and AHP	Suitability analysis for optimal land utilization for agricultural use	Regional (Tabriz County, Iran)
Zhuang, et al.	2011	Overlay analysis with binary thresholds	Identification of China's potential for five **bioenergy species**	National (China)
Schweers et al.	2011	Overlay analysis with multiple input criteria	Identification of China's potential areas for **biomass production**	National (China)
Cai, Zhang, & Wang	2011	Fuzzy logic and boolean knockout	Potential for second-generation **biofuel feedstocks** and low-input high-diversity (LIHD) mixtures of native perennials modelling	Global

Author	Date	GIS method	Purpose	Scale
Chandio et al.	2011	AHP and WLC	Determination of land suitability for urban development	Local (public parks of Larkana city pakistan)
Mustafa et al.	2011	MCE and AHP	Analysis of land suitability for different crops	Local (Kheragarh tehsil, Agra district India)
Milbrandt & Overend	2009	Overlay analysis with linear combination of multiple input criteria - binary thresholds	Lignocellulosic **biomass plants** potential mapping on marginal land in APEC countries	Semi-Global (APEC countries)
Lovett et al.	2009	Multi-criteria suitability analysis	Implications analysis of Miscanthus increased **biomass cropping**	National (Whales & England)
Baja, Chapman, & Dragovich	2002	Fuzzy methodology	Development of land suitability indices for agricultural land use	Local (the lower Hawkesbury-Nepean River catchment)

Land suitability assessment often requires combinations of methods such as linear overlays (Boolean criteria), Weighted Linear Combination (WLC), Ordered Weighted Average (OWA), Analytical Hierarchy Process (AHP) and Fuzzy Logic.

Many GIS suitability models assume that input criteria exhibit crisp boundaries between different land categories, which does not accurately represent physical variables since the reality is often more continuous. Employing continuous grades of marginality by using a ranking approach to standardize the input criteria instead of binary thresholds improves the quality of the results (Lewis & Kelly, 2014; Tenerelli & Carver, 2012).

6.3 Methodology for the development of the SEEMLA GIS tools

The development of the GIS tools requires the following steps:

1. Define the problems
2. Break the problems into sub-models
3. Determine significant layers
4. Define the analysis method
5. Reclassify or transform the data
6. Weight the input layers
7. Combine the layers
8. Analyze

The SEEMLA GIS tools will be developed as a toolbox for ESRI ArcGIS, comprising the following functionalities:

1. **SQR score calculation & Identification of marginal lands (SQR tool)**
   Input data: SQR parameters (selected spatial datasets in cooperation with BTU CS) – selected datasets from Annex I
   Output: SQR raster dataset and thematic map for Europe
   Coverage: EU 28 and Ukraine, depending on data availability
   Units: The final SQR-score ranges from 0 to 100 points.

Reclassification of the input datasets is required in order to assign scores and weights to each variable based on the Muencheberg SQR field manual. The SQR index will be calculated using Weighted Linear Overlay of the spatial datasets.

The SQR tool accuracy will be tested by comparing its output dataset to the existing map of *Soil quality rating for cropland in Germany,* developed by the BGR - Federal Institute for Geosciences and Natural Resources (resolution 250 m)[12]. This map was produced taking into account only drought risk and soil depth above solid rock as hazard indicators in the SQR calculation, since these indicators have the greatest effect on potential grain yield. The SEEMLA approach will include all land uses and not only arable land and will also incorporate acidification and content of coarse particles as hazard risks into the analysis.

2. **Exclusion of marginal lands unsuitable for biomass production for bioenergy (Bioenergy Suitability)**
   Input data: MagLs identified based on the SQR scores (<40), Elimination criteria & MagL indicators
   Output: Marginality maps per sub-category (10 maps) and overall map of marginal lands suitable for bioenergy crops - raster dataset and thematic map, & raster datasets
   Coverage: EU 28 and Ukraine, depending on data availability
   Units: Binary (0, 1) representing non marginal and marginal lands correspondingly

The tool will exclude areas that cannot be used for growing bioenergy crops. This step will reduce the volume of the data that will be analyzed. Then, marginal lands will be classified based on the constraining factors for growing crops, following the 10 sub-categories determined in deliverable 2.3 (Tables 2 & 4). The tool will produce one map for each marginality sub-category and also an overall marginality map, deriving from the geometric union of the 10 maps and additional parameters (Table 5). Selection by attributes and linear overlay of the datasets will be applied at this stage.

3. **Identification of bioenergy crops for marginal lands (Crops4MagLs)**
   Input data: Elimination & selection criteria

[12] https://produktcenter.bgr.de/terraCatalog/DetailResult.do?fileIdentifier=3DBC11EE-81E9-41A2-916E-1281DDD6C7A8

Output: Suitability maps for each bioenergy crop - raster dataset and thematic map

Coverage: EU 28 and Ukraine, based on data availability

Units: Binary (0, 1) representing unsuitable and suitable lands correspondingly

This tool will determine which crops are suitable for each marginal land, based on their ecological demands (Table 4), resulting in suitability maps for each bioenergy crop. Selection by attributes will be applied to identify suitable crops for MagLs.

The user will have to provide values for the parameters described in Table 6 for each land parcel, in order for the system to perform calculations and identify which crop can be grown at the specific land parcel.

4. Rating of marginal lands (RMagLs)

Input data: Ranking criteria (overall map of marginal lands, SQR map and economic data)

Output: Rating MagLs for bioenergy crops - raster dataset and thematic map

Coverage: EU 28 and Ukraine, depending on data availability

Units: Ranking using fuzzy logic based on suitability

This tool will classify marginal lands based on their overall potential for biomass production, taking into account the SQR score and also the cost efficiency of cultivating the specific land parcel.

Geospatial datasets contain attribute or/ and geometry inaccuracies. Inaccuracies mainly occur in the definition of the classes (attribute data) and in the measurement of the parameters. Both of these sources can result in imprecise assignment of cells to specific classes, when modelling parameters using numerical variables and constraints with crisp thresholds (ESRI, 2016). Substituting numerical values with linguistic variables reduces the required amount of precision and allows the representation of imprecise concepts to determine their relative importance as ranking criteria (Lewis & Kelly, 2014; Malczewski, 2002; Tenerelli & Carver, 2012).

Fuzzy logic addresses situations with unclear boundaries between classes, such as site selection and suitability analysis. Unlike crisp sets, fuzzy logic does not examine if a value is in or out of the class; it defines how likely it is that the phenomenon is a member of a set or class (ESRI, 2016).

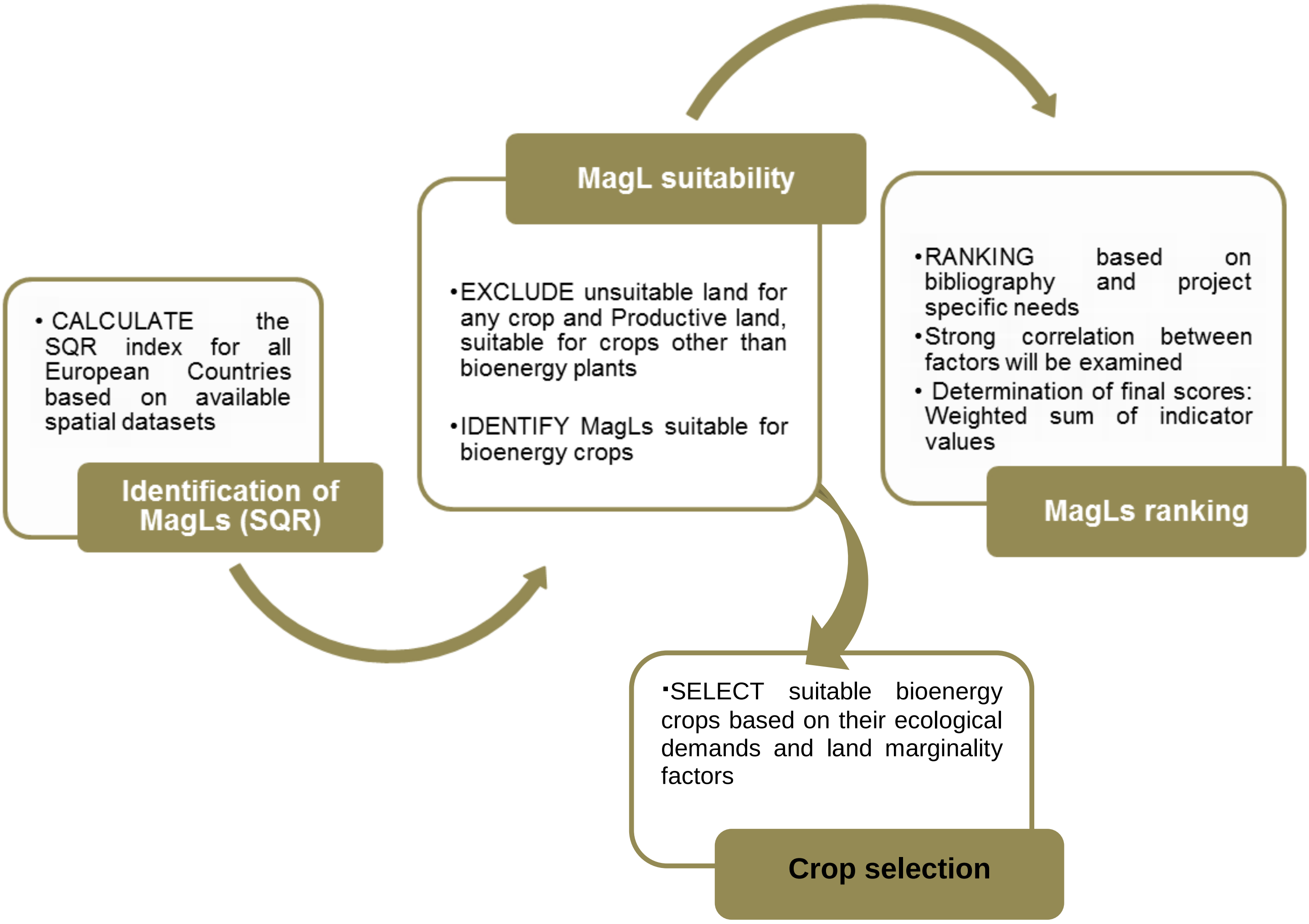

Figure 5. SEEMLA tools interoperability

The available datasets for the GIS analysis are listed in Annex I. First, which datasets will be used has to be determined, based mostly on their spatial and temporal coverage, as well as pixel size. Only raster datasets will be used, which then have to be processed before being used as inputs for the tools.

Due to the fact that they come from different sources they require resampling, projection and reclassification in some cases in order to be standardized. The projection used will be ETRS89 Lambert Azimuthal Equal Area for all raster datasets and thematic maps.

6.4 Outputs

The GIS application will comprise the following components:

1. SEEMLA Arc Toolbox, incorporating the tools developed:
   → SQR score calculation & Identification of marginal lands – Raster dataset
   → Exclusion of marginal lands unsuitable for biomass production for bioenergy & classification of MagLs based on the sub-category of marginality – Marginality

thematic maps, thematic maps of the lands that are not considered marginal within the SEEMLA project & raster datasets
→ MagL types available for exploitation per bioenergy plant - Thematic maps & raster datasets
→ Classification of marginal lands - Thematic map & raster dataset
2. SEEMLA datasets, including databases and basemaps used as inputs for the GIS tools.
3. Conceptual framework and methodology for the GIS application

Moreover, the GIS tool will be made available through the EIONET (European Environment Information and Observation Network) site, following the criteria by the European Environment Agency for the integration of data into the Environmental data centers and their hosting infrastructure.

6.5 Issues of uncertainty and error

In order to develop an integrated GIS model it is important to present the user with information about the confidence intervals associated with the results of the analysis (Michele Crosetto et al., 2000; Feizizadeh & Blaschke, 2014; Lewis & Kelly, 2014; Ligmann-Zielinska & Jankowski, 2014; Saltelli et al., 2010).

National datasets vary by country in terms of accuracy, reference period, classification, etc. It is therefore essential to harmonize the data in order to use them in the GIS analysis. Global or European data are often outdated and available at coarse resolution. When these data are used as input to a GIS operation, the errors in the input will propagate to the output of the operation. The principal sources of GIS-MCDA uncertainty are due to errors and variability in model choice, system understanding, weighting factors, data used, and human judgment (Feizizadeh & Blaschke 2014).

To best incorporate error and uncertainty in land suitability analysis, four components should be examined: (1) accuracy of input criteria; (2) validation of final results; (3) error propagation, or the compounding of errors in input datasets through the model; and (4) sensitivity of the model outputs to inputs (Lewis & Kelly, 2014).

Therefore, the following points (4) will be considered in developing the GIS application:

(1) accuracy of input criteria will be provided for each dataset.

(2) validation of final results by comparing the SEEMLA results to available data, i.e.:

- SEEMLA pilot cases
- Soil quality rating for cropland in Germany 1:1,000,000
- Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)
- European map of soil suitability to provide a platform for most human activities (EU28)
- Most important & secondary limitation to agricultural use

(3) error propagation, or the compounding of errors in input datasets through the model will be assessed using uncertainty analysis (UA). UA allows the analyst to assess the uncertainty associated with the model output as the result of the propagation through the model of errors

in input data, and uncertainties in the model itself (e.g. uncertainty in model parameters, structures, assumptions and specifications) (Crosetto & Tarantola, 2001).

The Monte Carlo (MC) approach will be applied, which allows exploration of the full range of variation in the input factors and does not require assumptions about the model structure (Crosetto & Tarantola, 2001)

(4) sensitivity of the model outputs to inputs. Sensitivity analysis (SA) studies how the variations in the model output can be apportioned, quantitatively or qualitatively, to different sources of variation (i.e. how the given model depends upon the information fed into it) (Crosetto & Tarantola, 2001).

7 Summary

Marginal lands have received a lot of attention as potential sites for sustainable biomass production for bioenergy. However, the uncertainty arising from MagL classification and quantification is one of the major constraining factors for its potential use. These issues are addressed by the SEEMLA project through the development of an algorithm to identify and assess MagLs in Europe. Land marginality is based on the SQR system (Mueller et al., 2007) whereas other constraining factors (e.g. environmental, economic) are taken into account to estimate the MagL that is actually suitable and available for bioenergy cropping. The algorithm is incorporated into tools that aim to provide important information and support the decision-making process for the sustainable use of MagLs for biomass production. The tools comprise a web – based application and a toolbox for ESRI ArcGIS, which will both be available to the public.

8 Abbreviation list

AHP	Analytical Hierarchy Process
API	Application Programming Interface
BGR	Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe)
BTU & CS	Brandenburg Technical University Cottbus-Senftenberg
CEC	Cation Exchange Capacity
CSP	Carbon sequestration potential
DBMS	Database Management System
DUTH	Democritus University of Thrace
EC	Electric Conductivity
EEA	European Environment Agency
EIONET	European Environment Information and Observation Network
ESDAC	European Soil Data Centre
ESP	Exchangeable sodium percentage
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FNR	Agency for Renewable Resources (Fachagentur Nachwachsende Rohstoffe e.V.)
GIS	Geographic Information System
IBC&SB	Institute for Bioenergy Crops & Sugar Beet of the National Academy of Agricultural Science
GUI	Graphical User Interface
IFEU	Institut für Energie- und Umweltforschung Heidelberg GmbH
IIASA	International Institute for Applied Systems Analysis
JRC	Joint Research Centre
LCA	Life-Cycle Assessment
MCDA	Multiple-Criteria Decision Analysis
MCE	Multi Criteria Evaluation
OWA	Ordered Weighted Average
PHP	Hypertext Preprocessor
SOC	Soil Organic Carbon
SQR	Soil Quality Rating
UNEP	United Nations Environment Programme
WLC	Weighted Linear Combination

9 References

Akinci, H., Özalp, A. Y., & Turgut, B. (2013). Agricultural land use suitability analysis using GIS and AHP technique. *Computers and Electronics in Agriculture*, *97*, 71–82. http://doi.org/10.1016/j.compag.2013.07.006

Allen, B., Kretschmer, B., Baldock, D., Menadue, H., Nanni, S., & Tucker, G. (2014). *Space for energy crops – assessing the potential contribution to Europe's energy future. Report produced for BirdLife Europe, European Environmental Bureau and Transport & Environment.* IEEP, London.

Arbia, G., Griffith, D., & Haining, R. (1998). Error propagation modelling in raster GIS: overlay operations. *International Journal of Geographical Information Science*, *12*(2), 145–167. http://doi.org/10.1080/136588198241932

Baja, S., Chapman, D. M., & Dragovich, D. (2002). Using Remote Sensing and GIS for Assessing and Mapping Land Use and Land Qualities in the Using Remote Sensing and GIS for Assessing and Mapping Land Use and Land Qualities in the Hawkesbury-Nepean River Catchment , Australia. *Geocarto International*, *17*(3), 37–41. http://doi.org/10.1080/10106040208542240

Biggs, A. (2007). The landscape and marginal cropping lands - inherent and induced. *Tropical Grasslands*, *41*, 133–138.

Cai, X., Zhang, X., & Wang, D. (2011). Land availability for biofuel production. *Environmental Science and Technology*, *45*(1), 334–339. http://doi.org/10.1021/es103338e

Caldas, M. M., Bergtold, J. S., Peterson, J. M., Graves, R. W., Earnhart, D., Gong, S., … Brown, J. C. (2014). Factors affecting farmers' willingness to grow alternative biofuel feedstocks across Kansas. *Biomass and Bioenergy*, *66*, 223–231. http://doi.org/10.1016/j.biombioe.2014.04.009

Chandio, I. A., Matori, A. N., Lawal, D. U., & Sabri, S. (2011). GIS-based land suitability analysis using AHP for public parks planning in Larkana City. *Modern Applied Science*, *5*(4), 177–189. http://doi.org/10.5539/mas.v5n4p177

Cowie, A. L., Smith, P., & Johnson, D. (2006). Does soil carbon loss in biomass production systems negate the greenhouse benefits of bioenergy? *Mitigation and Adaptation Strategies for Global Change*. http://doi.org/10.1007/s11027-006-9030-0

Crosetto, M., & Tarantola, S. (2001). Uncertainty and sensitivity analysis: tools for GIS-based model implementation. *International Journal of Geographical Information Science*, *15*(April), 415–437. http://doi.org/10.1080/13658810110053125

Crosetto, M., Tarantola, S., & Saltelli, A. (2000). Sensitivity and uncertainty analysis in spatial modelling based on GIS. *Agriculture, Ecosystems and Environment*, *81*(1), 71–79. http://doi.org/10.1016/S0167-8809(00)00169-9

Dale, V. H., Kline, K. L., Wiens, J., & Fargione, J. (2010). *Biofuels: Implications for land use and biodiversity*. *Ecological Society of America. Biofuels and Sustainabilty Reports*.

ESRI. (2016). Applying fuzzy logic to overlay rasters. Retrieved February 13, 2017, from http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/applying-fuzzy-logic-to-overlay-rasters.htm

European Union. REGULATION (EU) No 1305/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 december 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005. Annex III, Pub. L. No. No 1305/2013 (2013).

Feizizadeh, B., & Blaschke, T. (2012). Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS. *Journal of Environmental Planning &*

Management, *56*(1), 1–23. http://doi.org/10.1080/09640568.2011.646964

Feizizadeh, B., & Blaschke, T. (2014). An uncertainty and sensitivity analysis approach for GIS-based multicriteria landslide susceptibility mapping. *International Journal of Geographical Information Science*, *28*(3), 610–638. http://doi.org/10.1080/13658816.2013.869821

Fu, J., Jiang, D., Huang, Y., Zhuang, D., & Ji, W. (2014). Evaluating the Marginal Land Resources Suitable for Developing Bioenergy in Asia. *Advances in Meteorology*, *2014*, 9. http://doi.org/10.1155/2014/238945

Gopalakrishnan, G., Negri, C. M., & Snyder, S. W. (2011). A Novel Framework to Classify Marginal Land for Sustainable Biomass Feedstock Production. *Journal of Environment Quality*, *40*(5), 1593–1600. http://doi.org/10.2134/jeq2010.0539

Hart, K., Allen, B., Lindner, M., Keenleyside, C., Burgess, P., Eggers, J., & Buckwell, A. (2013). *Land As an Environmental Resource Final Report*.

Heuvelink, G. B. M., Burrough, P., & Stein, A. (1989). Propagation of errors in spatial modelling with GIS. *International Journal of Geographical Information Systems*, *3*(4), 303–322. http://doi.org/10.1080/02693798908941518

IIASA/FAO. (2012). Global Agro-ecological Zones (GAEZ v3.0). IIASA, Laxenburg, Austria and FAO, Rome, Italy. Retrieved from http://www.forg/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/

Joint Research Centre. (2014). *Updated common bio-physical criteria to define natural constraints for agriculture in Europe. Definition and scientific justification for the common criteria*. (J. Van Orshoven, M. Terres, & T. Tóth, Eds.)*JRC Science and Policy Reports. EUR 26638 EN*. Luxembourg. Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC89982/lbna26638enn.pdf

Kang, S., Post, W., Nichols, J., Wang, D., West, T., Bandaru, V., & Izaurralde, R. C. (2013). Marginal Lands: Concept, Assessment and Management. *Journal of Agricultural Science*, *5*(5), 129. http://doi.org/10.5539/jas.v5n5p129

Kang, S., Post, W., Wang, D., Nichols, J., Bandaru, V., & West, T. (n.d.). Hierarchical marginal land assessment for land use planning. *Land Use Policy*, *30*(1), 106–113. http://doi.org/10.1016/j.landusepol.2012.03.002

Kihoro, J., Bosco, N. J., & Murage, H. (2013). Suitability analysis for rice growing sites using a multicriteria evaluation and GIS approach in great Mwea region, Kenya. *SpringerPlus*, *2*(1), 265. http://doi.org/10.1186/2193-1801-2-265

Lewis, S., & Kelly, M. (2014). Mapping the Potential for Biofuel Production on Marginal Lands: Differences in Definitions, Data and Models across Scales. *ISPRS International Journal of Geo-Information*, *3*(2), 430–459. http://doi.org/10.3390/ijgi3020430

Ligmann-Zielinska, A., & Jankowski, P. (2014). Spatially-explicit integrated uncertainty and sensitivity analysis of criteria weights in multicriteria land suitability evaluation. *Environmental Modelling and Software*, *57*, 235–247. http://doi.org/10.1016/j.envsoft.2014.03.007

Liu, T. T., McConkey, B. G., Ma, Z. Y., Liu, Z. G., Li, X., & Cheng, L. L. (2011). Strengths, weaknessness, opportunities and threats analysis of bioenergy production on Marginal Land. *Energy Procedia*, *5*, 2378–2386. http://doi.org/10.1016/j.egypro.2011.03.409

Lovett, A. A., Sünnenberg, G. M., Richter, G. M., Dailey, A. G., Riche, A. B., & Karp, A. (2009). Land use implications of increased biomass production identified by gis-based suitability and yield mapping for miscanthus in england. *Bioenergy Research*, *2*(1–2), 17–28. http://doi.org/10.1007/s12155-008-9030-x

Lu, L., Jiang, D., Zhuang, D., & Huang, Y. (2012). Evaluating the marginal land resources suitable for developing Pistacia chinensis-based biodiesel in China. *Energies*, *5*(7), 2165–2177. http://doi.org/10.3390/en5072165

Malczewski, J. (2002). Fuzzy Screening for Land Suitability Analysis. *Geographical and Environmental Modelling*, *6*(1), 27–39. http://doi.org/10.1080/13615930220127279

Malczewski, J. (2006). GIS based multicriteria decision analysis: a survey of the literature. *International Journal of Geographical Information Science*, *20*(7), 703–726. http://doi.org/10.1080/13658810600661508

Milbrandt, A., & Overend, R. P. (2009). *Assessment of Biomass Resources from Marginal Lands in APEC Economies*.

Montgomery, B., Dragicevic, S., Dujmovic, J., & Schmidt, M. (2016). A GIS-based Logic Scoring of Preference method for evaluation of land capability and suitability for agriculture. *Computers and Electronics in Agriculture*, *124*, 340–353. http://doi.org/10.1016/j.compag.2016.04.013

Mueller, L., Schindler, U., Behrendt, A., Eulenstein, F., & Dannowski, R. (2007). *The Muencheberg Soil Quality Rating (SQR): FIELD MANUAL FOR DETECTING AND ASSESSING PROPERTIES AND LIMITATIONS OF SOILS FOR CROPPING AND GRAZING* (Vol. 2014). Muencheberg, Germany. Retrieved from http://www.zalf.de/en/forschung/institute/lwh/mitarbeiter/lmueller/Documents/field_mueller.pdf

Mustafa, A., Singh, M., Sahoo, R. N., Ahmed, N., Khanna, M., Sarangi, A., & Mishra, A. (2011). Land Suitability Analysis for Different Crops : A Multi Criteria Decision Making Approach using Remote Sensing and GIS. *Researcher*, *3*(12), 61–84.

Nakos, G. (1991). *Classification, mapping and evaluation of lands - Technical Specifications*. Athens.

Nelson, M., Dudal, R., Gregersen, H., Jodha, N., Nyamai, D., Groenwold, J.-P., & Torres, F. (1997). *Report of the study on CGIAR Research Priorities for Marginal Lands*. *TAC Secretariat, FAO*. Rome, Italy. Retrieved from http://www.fao.org/wairdocs/tac/x5784e/x5784e00.htm#Contents

Niu, X., & Duiker, S. W. (2006). Carbon sequestration potential by afforestation of marginal agricultural land in the Midwestern U.S. *Forest Ecology and Management*, *223*(1–3), 415–427. http://doi.org/10.1016/j.foreco.2005.12.044

Panagos, P., Van Liedekerke, M., Jones, A., & Montanarella, L. (2012). European Soil Data Centre: Response to European policy support and public data requirements. *Land Use Policy*, *29*(2), 329–338. http://doi.org/10.1016/j.landusepol.2011.07.003

Saltelli, A., Annoni, P., Azzini, I., Campolongo, F., Ratto, M., & Tarantola, S. (2010). Variance based sensitivity analysis of model output. Design and estimator for the total sensitivity index. *Computer Physics Communications*, *181*(2), 259–270. http://doi.org/10.1016/j.cpc.2009.09.018

Schweers, W., Bai, Z., Campbell, E., Hennenberg, K., Fritsche, U., Mang, H. P., … Zhang, N. (2011). Identification of potential areas for biomass production in China: Discussion of a recent approach and future challenges. *Biomass and Bioenergy*, *35*(5), 2268–2279. http://doi.org/10.1016/j.biombioe.2011.02.034

Skevas, T., Swinton, S. M., & Hayden, N. J. (2014). What type of landowner would supply marginal land for energy crops? *Biomass and Bioenergy*, *67*, 252–259. http://doi.org/10.1016/j.biombioe.2014.05.011

Tenerelli, P., & Carver, S. (2012). Multi-criteria, multi-objective and uncertainty analysis for agro-energy spatial modelling. *Applied Geography*, *32*(2), 724–736. http://doi.org/10.1016/j.apgeog.2011.08.013

Zabihi, H., Ahmad, A., Vogeler, I., Said, M. N., Golmohammadi, M., Golein, B., & Nilashi, M. (2015). Land suitability procedure for sustainable citrus planning using the application of the analytical network process approach and GIS. *Computers and Electronics in Agriculture*, *117*, 114–126. http://doi.org/10.1016/j.compag.2015.07.014

Zhang, J., Su, Y., Wu, J., & Liang, H. (2015). GIS based land suitability assessment for tobacco production using AHP and fuzzy set in Shandong province of China. *Computers and Electronics in Agriculture*, *114*, 202–211. http://doi.org/10.1016/j.compag.2015.04.004

Zhuang, D., Jiang, D., Liu, L., & Huang, Y. (2011). Assessment of bioenergy potential on marginal land in China. *Renewable and Sustainable Energy Reviews*, *15*(2), 1050–1056. http://doi.org/10.1016/j.rser.2010.11.041

Zoccali, P., Malacrinò, A., Campolo, O., Laudani, F., Algeri, G. M., Giunti, G., … Palmeri, V. (2017). A novel GIS-based approach to assess beekeeping suitability of Mediterranean lands. *Saudi Journal of Biological Sciences*. http://doi.org/10.1016/j.sjbs.2017.01.062

Zolekar, R. B., & Bhagat, V. S. (2015). Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach. *Computers and Electronics in Agriculture*, *118*, 300–321. http://doi.org/10.1016/j.compag.2015.09.016

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10 Annex I. List of spatial datasets reviewed for the SEEMLA project[13]

No	DATA SOURCE	DATASET	UNITS	SQR	MAGL CRITERIA	BIO ENERGY CROPS	VALIDATION CRITERIA	REFERENCE PERIOD	REFERENCE SYSTEM	RESOLUTION	COVER	URL
1.	High-resolution gridded datasets (and derived products) climatological data	TMP: near-surface mean temperature	°C	x	x	x		1901-2015	WGS84	0.5°	Global	https://crudata.uea.ac.uk/cru/data/hrg/
2.		TMN: near-surface minimum temperature	°C		x	x						
3.		TMX: near-surface temperature maximum	°C		x	x						
4.		DTR: near-surface diurnal temperature range	°C									
5.		PRE: precipitation	mm	x		x						
6.		WET: wet day frequency	days									
7.		FRS: frost day frequency	days									
8.		VAP: vapour pressure	hPa									
9.		CLD: cloud cover	%									
10.	WorldClim - Global Climate Data - Free climate data for ecological modeling and GIS	Precipitation	mm	x		x		1960-1990		1 km		http://www.worldclim.org/
11.		Elevation	m	x		x						
12.		tmax	°C			x						
13.		tmean	°C	x		x						
14.		tmin	°C			x						
15.		BIO1 = Annual Mean Temperature	°C	x	x	x						
16.		BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))	°C									
17.		BIO3 = Isothermality (BIO2/BIO7) (* 100)	dimensionless									
18.		BIO4 = Temperature Seasonality (standard deviation *100)	°C									
19.		BIO5 = Max Temperature of Warmest Month	°C			x						
20.		BIO6 = Min Temperature of Coldest Month	°C			x						
21.		BIO7 = Temperature Annual Range (BIO5-BIO6)	°C									
22.		BIO8 = Mean Temperature of Wettest Quarter	°C									
23.		BIO9 = Mean Temperature of Driest Quarter	°C									
24.		BIO10 = Mean Temperature of Warmest Quarter	°C									
25.		BIO11 = Mean Temperature of Coldest Quarter	°C									
26.		BIO12 = Annual Precipitation	mm	x	x	x						
27.		BIO13 = Precipitation of Wettest Month	mm									

[13] Datasets that may be useful for each process are marked with an X in the corresponding column (SQR, MagL identification, bioenergy crops, SEEMLA algorithm validation)

No	DATA SOURCE	DATASET	UNITS	SQR	MAGL CRITERIA	BIO ENERGY CROPS	VALIDATION CRITERIA	REFERENCE PERIOD	REFERENCE SYSTEM	RESOLUTION	COVER	URL
28.	WorldClim - Global Climate Data - Free climate data for ecological modeling and GIS	BIO14 = Precipitation of Driest Month	mm	x		x		1960-1990	WGS84	1 km	Global	http://www.worldclim.org/
29.		BIO15 = Precipitation Seasonality (Coefficient of Variation)	mm									
30.		BIO16 = Precipitation of Wettest Quarter	mm									
31.		BIO17 = Precipitation of Driest Quarter	mm	x								
32.		BIO18 = Precipitation of Warmest Quarter	mm									
33.		BIO19 = Precipitation of Coldest Quarter	mm									
34.	European Soil Data Centre	Potential threats to soil biodiversity in Europe	categories			x		2015	ETRS89 LAEA	500 m	EU(27 Countries - Croatia was not included)	http://esdac.jrc.ec.europa.eu/content/potential-threats-soil-biodiversity-europe
35.		Soil erosion by water (RUSLE2015)	t ha^{-1} yr^{-1}					2010	ETRS89 LAEA	100 m	EU28	http://eusoils.jrc.ec.europa.eu/content/soil-erosion-water-rusle2015
36.		Topsoil physical properties for Europe (based on LUCAS topsoil data)	%	X		x		2015	ETRS89 LAEA	500 m	EU28 + Balkan + Switzerland + Norway	
37.		LS-factor (Slope Length and Steepness factor) for the EU	dimensionless	X				2015	ETRS89 LAEA	25m and 100m	EU28	http://eusoils.jrc.ec.europa.eu/content/ls-factor-slope-length-and-steepness-factor-eu
38.		Soil erosion in forestland in Europe	Mg ha^{-1} yr $^{-1}$					2010	ETRS89 LAEA	100 m	EU28	http://esdac.jrc.ec.europa.eu/content/soil-erosion-forestland-europe-using-rusle2015
39.		Topsoil Soil Organic Carbon (LUCAS) for EU25	g C kg-1					2015	ETRS89 LAEA	1 km	EU25 (excluded Romania, Bulgaria, Croatia)	http://esdac.jrc.ec.europa.eu/content/topsoil-soil-organic-carbon-lucas-eu25
40.		Topsoil Organic Carbon Content for Europe (OCTOP) 0 - 30 cm	%					2004	ETRS89 LAEA	1 km	EU28	http://esdac.jrc.ec.europa.eu/content/octop-topsoil-organic-carbon-content-europe
41.		Soil Organic Carbon - Saturation Capacity in Europe	t C ha^{-1}					2016	ETRS89 LAEA	250 m	EU28 + Balkan + Norway	http://eusoils.jrc.ec.europa.eu/content/soil-organic-carbon-saturation-capacity
42.		Global Soil Organic Carbon Estimates	t/ha					2012	ETRS89 LAEA	30 arc seconds ≈ 1 km	Global	http://esdac.jrc.ec.europa.eu/content/global-soil-organic-carbon-estimates
43.		Soil pH in Europe	dimensionless	X		X		2009	ETRS89 LAEA	5 km	EU25 (Romania & Bulgaria are not included,)+Norway , Switzerland, Croatia, Albania	http://esdac.jrc.ec.europa.eu/content/soil-ph-europe
44.		Saline and Sodic Soils in the EU	%	X		X		2008	ETRS89 LAEA	1 km	EU27	http://esdac.jrc.ec.europa.eu/content/saline-and-sodic-soils-european-union
45.		Digital Elevation Model of Europe	m	X	X	X		2008	ETRS89 LAEA	1 km	EU26	http://esdac.jrc.ec.europa.eu/content/heavy-metals-topsoils
46.		Heavy metals in topsoil (arsenic, cadmium, chromium, copper, mercury, nickel, lead and zinc)	binary (0, 1)		X			2008	ETRS89 LAEA	5 km	EU26	http://esdac.jrc.ec.europa.eu/content/heavy-metals-topsoils

No	DATA SOURCE	DATASET	UNITS	SQR	MAGL CRITERIA	BIO ENERGY CROPS	VALIDATION CRITERIA	REFERENCE PERIOD	REFERENCE SYSTEM	RESOLUTION	COVER	URL
47.	European Soil Data Centre	European Landslide Susceptibility Map	categories					2013	ETRS89 LAEA	1 km	EU26	http://esdac.jrc.ec.europa.eu/content/european-landslide-susceptibility-map-elsus1000-v1
48.		Soil Erodibility (K- Factor) High Resolution dataset for Europe	t ha h ha^{-1} MJ^{-1} mm^{-1}					2014	ETRS89 LAEA	500 m	EU28+Norway, Switzerland, Balkan states, Moldova and Ukraine	http://esdac.jrc.ec.europa.eu/content/soil-erodibility-k-factor-high-resolution-dataset-europe#tabs-0-description=0
49.		Soil hydraulic properties for Europe	cm3/cm3 & cm/day					2016	ETRS89 LAEA	1 km	EU + Balkan + Norway	http://esdac.jrc.ec.europa.eu/content/maps-indicators-soil-hydraulic-properties-europe#tabs-0-description=0
50.		Soil Biomass Productivity maps of grasslands and pasture, of croplands and of forest areas in the European Union (EU27)	scores 0 - 10				X	2013	ETRS89 LAEA	1 km	EU28 minus Croatia	http://esdac.jrc.ec.europa.eu/content/soil-biomass-productivity-maps-grasslands-and-pasture-coplands-and-forest-areas-european
51.		European map of soil suitability to provide a platform for most human activities (EU28)	categories			X	X	2016	ETRS89 LAEA	1 km	EU28	http://eusoils.jrc.ec.europa.eu/content/european-map-soil-suitability-provide-platform-most-human-activities-eu28
52.		Most important limitation to agricultural use	categories	X		X	X	2008	WGS84	-	EU27	http://eusoils.jrc.ec.europa.eu/content/google-earth-files
53.		Secondary limitation to agricultural use	categories	X		X	X					
54.		STR_TOP = Topsoil structure	categories	X		X						
55.		PD_TOP = Topsoil packing density	categories									
56.		PD_SUB = Subsoil packing density	categories	X								
57.		Full soil code of the STU from the World Reference Base (WRB) for Soil Resources	categories									
58.		TEXT-SRF-DOM. Dominant surface textural class of the STU.	%									
59.		IL. Code for the presence of an impermeable layer within the soil profile of the STU.	cm									
60.		ROO. Depth class of an obstacle to roots within the STU.	cm			X						
61.		WR. Dominant annual average soil water regime class of the soil profile of the STU.	cm	X								
62.		OC_TOP. Topsoil organic carbon content.	%									
63.		Peat	binary (0, 1)									
64.		DR. Depth to rock.	cm	X		X						
65.		DGH. Depth to a gleyed horizon.	cm		X	X						
66.		DIMP. Depth to an impermeable layer.	cm	X		X						
67.		Soil erodibility class.	categories									

No	DATA SOURCE	DATASET	UNITS	SQR	MAGL CRITERIA	BIO ENERGY CROPS	VALIDATION CRITERIA	REFERENCE PERIOD	REFERENCE SYSTEM	RESOLUTION	COVER	URL
68.	European Soil Data Centre	Area of STU allocation	binary (0, 1)					2013	ETRS89 LAEA	1 km	Europe	http://eusoils.jrc.ec.europa.eu/content/european-soil-database-derived-data#tabs-0-description=0
69.		Depth available to roots	cm			X						
70.		Clay content (topsoil & subsoil)	%	X		X						
71.		Sand content (topsoil & subsoil)	%	X		X						
72.		Silt content (topsoil & subsoil)	%	X		X						
73.		Organic carbon content (topsoil & subsoil)	%									
74.		Bulk density (topsoil & subsoil)	g cm^{-3}	X								
75.		Coarse Fragments (topsoil & subsoil)	%	X								
76.		Total available water content from PTR (topsoil & subsoil)	mm									
77.		Total available water content from PTF (topsoil & subsoil)	mm									
78.	ISRIC	WISE derived soil property estimates on a 30 by 30 arcsec global grid	categories					2016	WGS84	30 arc-seconds	Global	
79.	FAO	Global Assessment of Human-induced Soil Degradation (GLASOD)	categories					1987-1990	ETRS89 LAEA	-	Global	http://www.isric.org/projects/global-assessment-human-induced-soil-degradation-glasod
80.	FAO Harmonized World Soil Database v 1.2\ Terrain	Elevation	m			X		2008	WGS84	30 arc-seconds≈ 10 km	Global	http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/
81.		Slopes	%	X		X						
82.		Aspect	degrees			X						
83.	FAO Harmonized World Soil Database v 1.2\ Land Use and Land Cover	Rain-fed cultivated land	%									
84.		Irrigated cultivated land, according to GMIA 4.0	%		X							
85.		Total cultivated land	%									
86.		Forest land, calibrated to FRA2000 land statistics	%									
87.		Grass/scrub/woodland	%									
88.		Built-up land (residential and infrastructure)	%									
89.		Barren/very sparsely vegetated land	%									
90.		Mapped water bodies	categories		X							
91.	FAO Harmonized World Soil Database v 1.2\ Soil Qualities for Crop Production	Nutrient availability	categories	X		X						
92.		Nutrient retention capacity	categories			X						
93.		Rooting conditions	categories			X						
94.		Oxygen availability to roots	categories			X						
95.		Excess salts	categories	X		X						
96.		Toxicity	categories	X	X	X						
97.		Workability (constraining field management)	categories		X							

No	DATA SOURCE	DATASET	UNITS	SQR	MAGL CRITERIA	BIO ENERGY CROPS	VALIDATION CRITERIA	REFERENCE PERIOD	REFERENCE SYSTEM	RESOLUTION	COVER	URL
98.	Federal Institute for Geosciences and Natural Resources (BGR)	Soil quality rating for cropland in Germany 1:1,000,000	scores 0 - 100				X	2013	ETRS89 LAEA	250 m	Germany	https://produktcenter.bgr.de/terraCatalog/DetailResult.do?fileIdentifier=3DBC11EE-81E9-41A2-916E-1281DDD6C7A8
99.	European Space Agency	GlobCover Land Cover Maps	categories		X			2009	WGS84	1/360°	Global	http://due.esrin.esa.int/page_globcover.php
100.	Biodiversity Information System for Europe	Map of European ecosystem types	categories		X			2015	ETRS89 LAEA	-	Europe	http://biodiversity.europa.eu/maes/mapping-ecosystems/map-of-european-ecosystem-types
101.	European Environment Agency	Natura 2000 data - the European network of protected sites	categories		X			2015	ETRS89 LAEA	-	Europe	http://www.eea.europa.eu/data-and-maps/data/natura-7/#parent-fieldname-title
102.		Nationally designated areas (CDDA)	categories		X			2016	ETRS89 LAEA	-	Europe	http://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-11#tab-gis-data
103.		Digital Elevation Model of Europe	m	X	X	X		2000	ETRS89 LAEA	30 m	Europe	http://www.eea.europa.eu/data-and-maps/data/eu-dem#tab-european-data
104.	Copernicus	Corine Land Cover (CLC) 2012, Version 18.5.1	categories		X			2011 - 2012	ETRS89 LAEA	-	EEA 39	http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012

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11 Annex IIa. Demands of SEEMLA bioenergy crops (complete list) - DUTH

Common name	Scientific name	Type of plant	Drought resistant	Annual rainfall (min -max)	Frost resistant	Lowest winter tempera-ture	Average day temperatures (min / max)	Optimum Average day temperatures	Altitudinal range (min - max)	Suitable for restora-tion	Soil						Soil pH (min - max)	Soil moisture	Land use
											Sandy	Highland acid moors	Limestone - rocky	Loam	Heavy clay	Peat			
1. Black locust	*Robinia pseudoacacia* L.	Woody	X	570 - 2 000 mm	-	- 12°C	-4 / 35°C	10 / 18°C	0 - 1040 m	X	X	X	X	X	X		4.5 - 8.2	well-drained	
2. Scots pine	*Pinus sylvestris* L.	Woody	X	240 - 1 780 mm	X	-36°C	-		0 - 2600 m	X	X	X					4.5 - 6	well-drained	
3. Black pine	*Pinus nigra*	Woody	X	350 - 2 200 mm	X	-30°C	-		800 - 1500 m	X	X		X	X	X		4 - 8	dry	
4. Basket willow	*Salix viminalis L.*	Woody	-	550 - 1 100 mm	X		-	20°C	0 - 570 m	X	X			X	X		5 - 7.5	moist, wet loamy soils	
5. Poplar	*Populus sp. L*	Woody	-	550 - 1 000 mm	X	- 29°C	-5 / 31°C	9 / 17°C	0 - 1200 m	X							4.5 - 7.5	wet	
6. Eucalyptus	*Eucalyptus sp.*	Woody	X	800 - 1 600 mm	-	-8°C	2 / 32°C	16 / 22°C	140 - 350 m	X	X			X			5.5 - 6.4	well-drained	
7. Tree of heaven	*Ailanthus altissima*	Woody	X	360 - 610 mm	X	-35°C	-10 / 32°C	7 / 18°C	20 - 2000 m	X			X	X			5.5 - 8	light moist soils	
8. Miscanthus giganteus	*Miscanthus × giganteus*	Herbaceous	-	400 - 800 mm	X	- 23°C	25 / 32°C	8.5°C	700 - 1000 m		X		X		X		5.5 - 7.5	moist, well-drained	
9. Switchgrass	*Panicum virgatum* L.	Herbaceous	X	380 - 760 mm	X	- 22°C	10 / 29°C	10 / 18°C	0 - 700 m	X	X		X	X			5 - 7	moderately to well-drained	Excellent plant for riparian buffer strips or on other sensitive lands
10. Columbus grass	*Sorghum × almum*	Herbaceous	X	460 - 1 900 mm	-	- 15°C	15 / 22°C	8.4 / 23.5°C	0 - 700 m					X	X		6.5 - 6.5	well-drained	
11. Reed canary grass	*Phalaris arundinacea* L.	Herbaceous	X	300 - 650 mm	X	-39°C	-	20°C	-		X						6.1 - 7.5	moist	Cultivated floodplains and peatlands
12. Sida	*Sida hermaphrodita*	Herbaceous	X	500 mm	X	-35°C	-		-	X							5.5 - 8	wet	
13. Jerusalem artichoke	*Helianthus tuberosus* L.	Herbaceous	-	300 - 2 820 mm	X	-30°C	6.3 / 26.6 °C		300 - 750 m	-	X			X	X		4.5 - 8.2	well-drained	
14. Cup plant	*Silphium perfoliatum* L.	Herbaceous	X	160 - 510 mm	X	-35°C	-	20 °C	-		X			X			6.6 - 7.8	moist to dry	
15. Giant knotweed	*Fallopia sachalinensis*	Herbaceous	X	500 - 1 200 mm	X	-40°C	4 / 8°C		0 - 1050 m	X	X			X	X		7 - 7	moist	Canals, ditches, stream banks, lakeshores, beaches
16. Giant reed	*Arundo donax* L.	Herbaceous	-	300 - 4 000 mm	-		7 / 29°C	24 / 30°C	0 - 4000 m	X	X					X	6.5 - 7.5	high groundwater level	
17. Common reed	*Phragmites australis*	Herbaceous	-	310 - 2 410 mm	X	- 20°C	6.6 / 35°C	30 / 35°C	0 - 2100 m	X	X				X		4.8 - 8.2	light swampy flooded peat soils	Peatlands, floodplains, swamps, drains and moist headlands
18. Cardoon	*Cynara cardunculus* L.	Herbaceous	X	400 - 860 mm	X	- 23°C	10 / 22°C		0 - 500 m	X	X			X	X		7 - 7	capacity of retaining water along the soil profile	Disturbed, open sites in grasslands, chaparral, coastal sage scrub, and riparian areas; abandoned agricultural fields

12 Annex IIb. Demands of SEEMLA bioenergy crops (complete list) – DUTH - To be revised in WP6

Common name	Scientific name	Yield	Rotation period	Energy output	Propagation
1. Black locust	*Robinia pseudoacacia* L.	17-40 t/ha/year		19.4 MJ/kg	seeds, root cuttings, root shoots and grafts
2. Scots pine	*Pinus sylvestris* L.	275 t/ha		19.52 kJ/kg	seeds
3. Black pine	*Pinus nigra*	144 - 171 t/ha	45 - 70 years	15.5 kJ/kg	seeds
4. Basket willow	*Salix viminalis L.*	12.4 - 22.7 t/ha/year	5 - 7 years	17 kJ/kg	cuttings
5. Poplar	*Populus sp. L*	9 - 15 t/ha	21 - 27 years	19 kJ/kg	cuttings
6. Eucalyptus	*Eucalyptus sp.*	5 - 13 t/ha		18.94 MJ/kg for wood and 16.46 MJ/kg for bark	seeds
7. Tree of heaven	*Ailanthus altissima*	N/A		19.5 kJ/kg	seeds & root sprouts
8. Miscanthus giganteus	*Miscanthus × giganteus*	5.3 t/ha of dry biomass		18 MJ / kg	seeds or parts of roots pre-planting soil treatment is required
9. Switchgrass	*Panicum virgatum* L.	12.4 - 25 t/ha	3 - 4 years	18.4kJ/kg	seeds, tillers, and rhizomes
10. Columbus grass	*Sorghum × almum*	6.0 - 6.5 t/ha of dry biomass		17 MJ / kg	seeds
11. Reed canary grass	*Phalaris arundinacea* L.	4.0-7.0 t/ha of dry biomass		16.9 MJ/kg	seeds
12. Sida	*Sida hermaphrodita*	22.6 - 24.4 t/ha of dry biomass		18.7 MJ/kg	seeds
13. Jerusalem artichoke	*Helianthus tuberosus* L.	16 - 20 t/ha		14 - 15 MJ/kg	tubers
14. Cup plant	*Silphium perfoliatum* L.	15 - 20 t/ha		17.3 MJ/kg	seeds
15. Giant knotweed	*Fallopia sachalinensis*	8 to 30 t/ha of dry matter		17.2 MJ/kg	seedlings or rhizomes
16. Giant reed	*Arundo donax* L.	19 to 35 t/ha of dry matter		17 MJ/kg	rhizomes or cuttings
17. Common reed	*Phragmites australis*	5 to 43 t/ha of dry biomass (Average yield: 15 t/ha)		16.9 MJ/kg	Mainly with seeds. Rhizomes or cuttings also possible. The reed well propagates itself on solar wetlands.
18. Cardoon	*Cynara cardunculus* L.	15 - 30 t/ha of dry biomass		17.6 MJ/kg	seeds

Annex II References

Bures (2016) Biofuel: Wood chips [online]
Available from http://www.burespro.com/cat/product/product/file/270/ [accessed 20/10/2016]

Eucalyptus (2016) [online]
Available from http://www.eucalyptus.gr/ [accessed 21/10/2016]

European Forest Genetic Resources Programme (2016) [online]
Available from < http://www.euforgen.org/> [accessed 11/11/2016]

Fernández J., Curt M.D. (2005) State of the art of Cynara cardunculus as an energy crop. In: Sjunnesson L., Carrasco J.E., Helm P., Grassi A. (Eds.), Proceedings of the 14th European Biomass Conference, Biomass for Energy, Industry and Climate Protection, 17-21 October, Paris, France. ETA-Renewable Energies and WIP Renewable Energies (Pub.), p.22-27.

Korakis, G. (2015) Forest botany. Indigenous trees and shrubs of Greece, Athens: Union of Greek Academic Libraries Available at http://hdl.handle.net/11419/742

Plants For A Future (PFAF) Database (2016) [online]
Available from < http://www.pfaf.org/user/Default.aspx> [accessed 8/11/2016]

San-Miguel-Ayanz, J., de Rigo, D., Caudullo, G., Houston Durrant, T., Mauri, A. (Eds.), 2016. European Atlas of Forest Tree Species. Publication Office of the European Union, Luxembourg

Śliż-Szkliniarz, B. (2013) Energy Planning in Selected European Regions : Methods for Evaluating the Potential of Renewable Energy Sources, Karlsruhe : KIT Scientific Publishing, Available from https://www.researchgate.net/profile/Beata_Sliz-Szkliniarz/publication/290096201_Energy_Planning_in_Selected_European_Regions_-_Methods_for_Evaluating_the_Potential_of_Renewable_Energy_Sources/links/56c1bc8208aee5caccf9057b.pdf

Stone, K. R. 2009. Robinia pseudoacacia. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available from: http://www.fs.fed.us/database/feis/ [accessed 24/10/2016].

United States Department of Agriculture (2016) Plants database [online]
Available from < https://plants.usda.gov/java/> [accessed 20/11/2016]