D4.1 e.s Report of pilot case study 1: Use of open-source platform and free satellite data to map and monitor MLs, executive summary

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

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Authors	Alfonso Abad (Cesefor), Elisa Bender (IABG), Laura Martín Collado (Cesefor), Michał Krupiński (CBK PAN), Ewa Gromny (CBK PAN), Marta Milczarek (CBK PAN)
Contributors	Dzhaner Emin (IABG), Franscisco Gallego Ciprés (Cesefor)
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[1] **R** = Report, **P** = Prototype, **D** = Demonstrator, **O** = Other
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MAIL CONSORTIUM

Aristotle University of Thessaloniki (AUTH) Greece	Industrieanlagen Betriebsgesellschaft MBH (IABG) Germany
Gounaris N. – Kontos K. OE (HOMEOTECH) Greece	Centrum Badan Kosmicznych Polskiej Akademii Nauk (CBK PAN) Poland
Universitat Politecnica de Valencia (UPV) Spain	Fundacion Centro De Servicios Y Promocion FOrestral Y de su Industria De Castilla y Leon (CESEFOR) Spain

ABBREVIATIONS

Term	Explanation
AHP	Analytical Hierarchy Process
AWC	Available Water Capacity
CLC	Corine Land Cover
CLC_CH	Corine Land Cover Change
CR	Consistency Ratio
EAFRD	European Agricultural Fund for Rural Development
FCC	fraction of tree cover
FEADER	European Agricultural Fund for Rural Development
GEE	Google Earth Engine
INIA	National Institute for Agrarian Innovation
ITACyL	Agrarian Technology Institute of Castile and León
MFE	Forest Map of Spain
ML	Marginal Land
MSDA	Multi Criteria Decision Analysis
OLC	Other Land Cover
PCM	Pairwise Comparison Matrix
REN	Protected Natural Areas
S2GLC	Sentinel2 Global Land Cover
SAGA	System for Automated Geoscientific Analyses
SIOSE	Spanish Land Cover and Land Use Information System
SQR	Soil Quality Rating

TCCM	Tree Cover Density Changes
TDM-FNF	TanDEM – Forest – Non-Forest
VEG YPEKA	Vegetation (Greek Ministry of Environment and Energy)

Contents

1. INTRODUCTION

This task aims at the development of marginality detection system per four Member States that participate in the ***MAIL*** project (Germany, Greece, Poland and Spain), based on open-source data. As a marginality detection system, we consider a GIS analysis based on national/ regional datasets that a priory will have better accuracy or better understanding of local aspects. The results of each system were further compared with the results of D2.3 in order to better understand marginality and its local aspects. Although results of Task 4.1 are focused on pilot case sites, marginality detection systems were developed on a wider extent depending on the availability of regional or national datasets.

Regarding **Germany**, it was decided to keep the overall concept of combining hard thresholds and soft constraints, but it was adapted to available data and regulations of the country. Protected areas play a big role in any form of planning and there are certain regulations to follow, which is why these areas are an important part of the hard thresholds and the used datasets more detailed compared to 2.3. Another focus of this methodology is using regional data for the soft constraints. In the case of Germany there are two options: data on a national level for the whole country, or data on a state level. Depending on the availability of suitable datasets, an individual combination of national and state data was used for each state. If no suitable data was available for important indicators the European data from 2.3 was used. Germany's system has **national extend** and focus on the pilot sites of Nochten and Welzow.

Regarding **Greece**, the same basic methodology was implemented which combines hard and soft thresholds based on national data. In the first step the hard layer of ML was defined. This was done with two different ways by selecting specific classes from two different datasets as proper basemaps for further process, one dataset was the CLC18 and the other the Vegetation Map of Greece coming from the Ministry of Environment and Energy. To that direction another three different masks were realized; the cores of absolute protection of Greek protected areas, the elevation zone >1200m and the steep slopes >45%. In the second step the soft layers were selected (slope, aspect, soil depth, erosion, rain and productivity capacity regarding Forestry). Then values were allocated per soft layer categories in order to perform an Analytic Hierarchy Process (AHP). The results led to production of two different datasets that were further compared with the deliverable D2.3. According to that the localized systems manage to perform better, as they describe sounder the local aspects/particularities. Furthermore, the product that based on the Vegetation Map that is coming from the Greek Ministry of Environment and Energy performs better that the one that comes from CLC18. Greece's system has **national extend** and focus on the pilot sites of Thessaloniki and Rhodope.

In case of **Poland** the area of Swietokrzyskie Vooivodship (province) was selected. The methodology was adjusted to regional condition on both stage: hard and soft constrains. Areas for exclusion were identified using only national topographic dataset, which provide more detailed range of land cover / land use classes, comparing to databases used in Task 2.3. In case of soft layers, only productivity parameters were modified by the usage of national soil quality map, while weights of specific layer groups were preserved, according to Task 2.3. The reasons for that were: lack of open access products in case of most layers, or lack of information (empty records) in the available ones. Poland's system has **regional extend**.

In the case of **Spain**, two models have been developed for the detection of marginal areas: the first at national level and the second at regional level with Castile and León as a reference. These scalable models are based on the national definition of forest land that considers a minimum tree cover of 10% and on the use of the national land use mapping (SIOSE). The SIOSE mapping is based on the multi-labelling of landscape functions and incorporates updated cadastral and national forest inventory information in a useful input to improve accuracy in the detection and analysis of MLs. The Marginal lands proposed for Spain consist of several potential sites that could be defined as Marginal Lands including semi-urban degraded lands and low productivity lands adjacent to natural parks and forest areas. Spain's systems have generic **national** and a more detailed **regional extend,** focusing on the pilot sites of "Tierras Altas" that is located in Soria province of Castile and León, the area of the Municipality of Nogueruelas (Teruel) in the Central Eastern part of the Iberian Peninsula, and "Sierra de Espadán" in the province of Castellón (region of Valencia).

In all cases the adaptions of the original methodology resulted in more precise results compared to 2.3. The previously used classification methods to rate the suitability of Marginal Lands have been applied as well and show similar results to each other, so certain areas can be interpreted as suitable or unsuitable with a strong reliability.

2. GERMANY

2.1 Site's location

Two test sites were chosen for Germany, they include lowland areas of productivity as well as post-mining areas. One is "Nochten", located in the northern part of Saxony and the other one "Welzow", located in the south of Brandenburg and next to (Figure 1). They have been selected as representative pilot sites because they include large post-mining areas that could be defined as Marginal Lands.

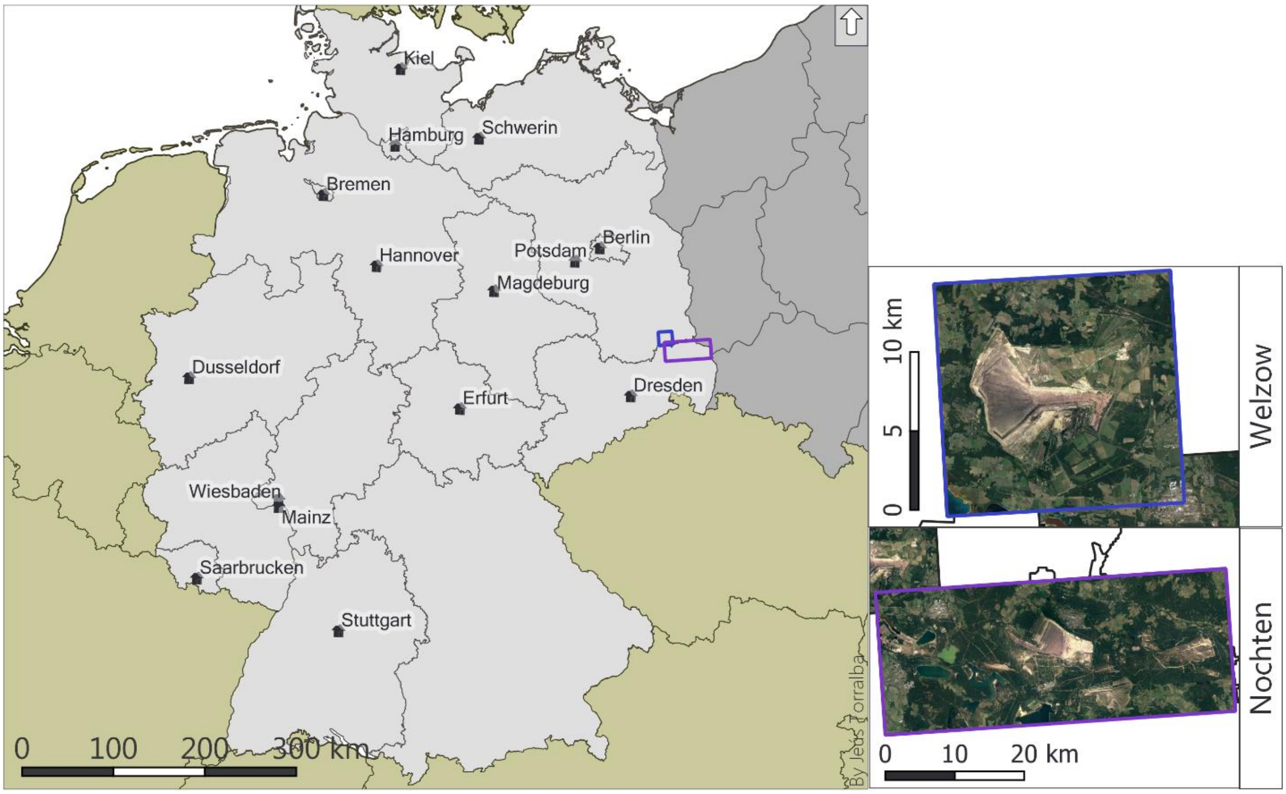

Figure 1. Germany (left) and the pilot sites of "Welzow" (outlined with blue) and "Nochten" (outlined with purple). Source: personal compilation of Jesús Torralba Pérez

2.2 Results and comparison

The following tables contain the calculated areas of MLs in the selected test sites "Nochten" and "Welzow" in hectares and percent. While Table 1 shows the results of task 2.3,

Table 2 shows the results retrieved from the adapted methodology of task 4.1.

Table 1: MLs areas for test sites in hectares and percent for each classification method following the 2.3 methodology. Source: Personal compilation of Elisa Bender

Pilot site	Total of ML	Classification Method	ML high	ML low	ML unsuitable
Nochten (Germany)	21120.5 (16.9%)	min - max	6.6 (0.01%)	2023.3 (1.62%)	19090.6 (15.31%)
		p25 - p75	1255.5 (1.01%)	17891.5 (14.35%)	1973.5 (1.58%)
		p33 – p66	1933.4 (1.55%)	14043.5 (11.26%)	5143.6 (4.13%)
Welzow (Germany)	6533.0 (26.3 %)	min - max	27.1 (0.11%)	1554.8 (6.26%)	4951.2 (19.95%)
		p25 - p75	1095.4 (4.41%)	5437.6 (21.91%)	0.0 (0.0%)
		p33 – p66	1581.1 (6.37%)	4952.0 (19.95%)	0.0 (0.0%)

Table 2: MLs areas for test sites in hectares and percent for each classification method following the 4.1 methodology. Source: Personal compilation of Elisa Bender

Pilot site	Total of ML	Classification Method	ML high	ML low	ML unsuitable
Nochten (Germany)	18924.0 (15.14%)	min - max	2479.0 (1.98%)	10767.5 (8.62%)	5677.5 (4.54%)
		p25 - p75	5883.25 (4.71%)	7373.5 (5.9%)	5667.25 (4.53%)
		p33 – p66	7216.25 (5.77%)	5960.25 (4.77%)	5747.5 (4.6%)
Welzow (Germany)	5960.75 (24.0%)	min - max	999.0 (4.02%)	3322.0 (13.37%)	1639.75 (6.6%)
		p25 - p75	2137.75 (8.61%)	2194 (8.83%)	1629 (6.56%)
		p33 – p66	2411.5 (9.71%)	1863 (7.5%)	1686.25 (6.79%)

Comparing the results of 2.3 and 4.1 it can be found that there is a slight decrease of MLs, 1.76% for the test site Nochten and 2.3% for Welzow. Overall, about 4% less Marginal Land was found for Germany as a whole (Table 3).

Table 3: Total area of Marginal Lands detected in Germany, for methodology 2.3 and 4.1. Source: Personal compilation of Elisa Bender

Methodology	Total country area (km^2)	ML area (km^2)	ML area (%)
2.3	357,340	41,606	11.64
4.1		27,113	7.59

In general comparison to 2.3, the classification methods of 4.1 categorize Marginal Lands quite evenly into the three classes. Just for method A the majority is classified as "Marginal lands with low plantation suitability". Altogether the results of method A, B and C are very similar to each other, and it is apparent which areas are suitable or unsuitable Marginal Lands, this can be seen in

Figure 3.

Comparing the visual results of 2.3 (Figure 2) and 4.1 with each other, it can be seen that areas, classified in 2.3 as "Marginal Lands with high plantation suitability", have been classified as "potentially unsuitable lands" in 4.1. This is very visible for the methods B and C.

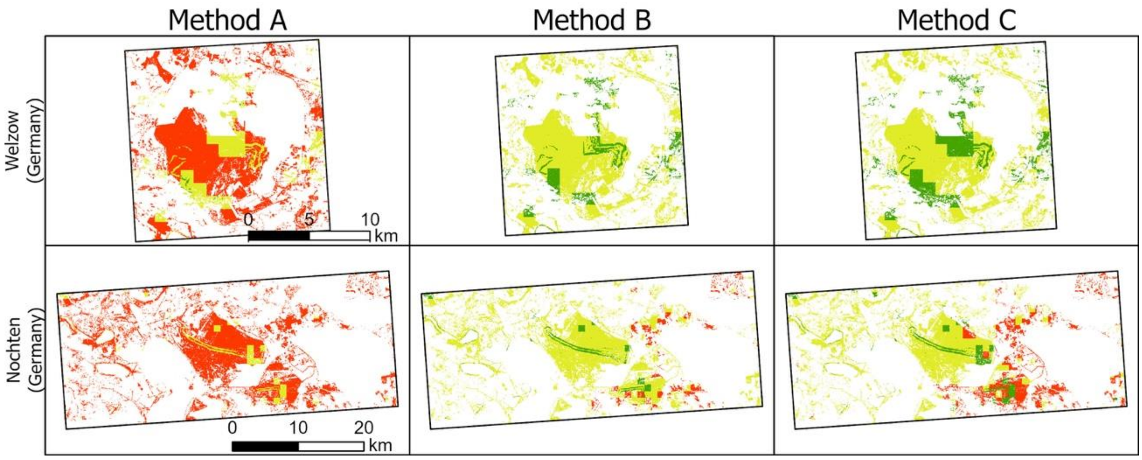

Figure 2: Final Layer of MLs (task 2.3) classified with 3 methods into the 3 categories: "Marginal lands with high plantation suitability" (green), "Marginal lands with low

plantation suitability" (yellow) and "Potentially unsuitable lands" (red). Source: Personal compilation of Elisa Bender

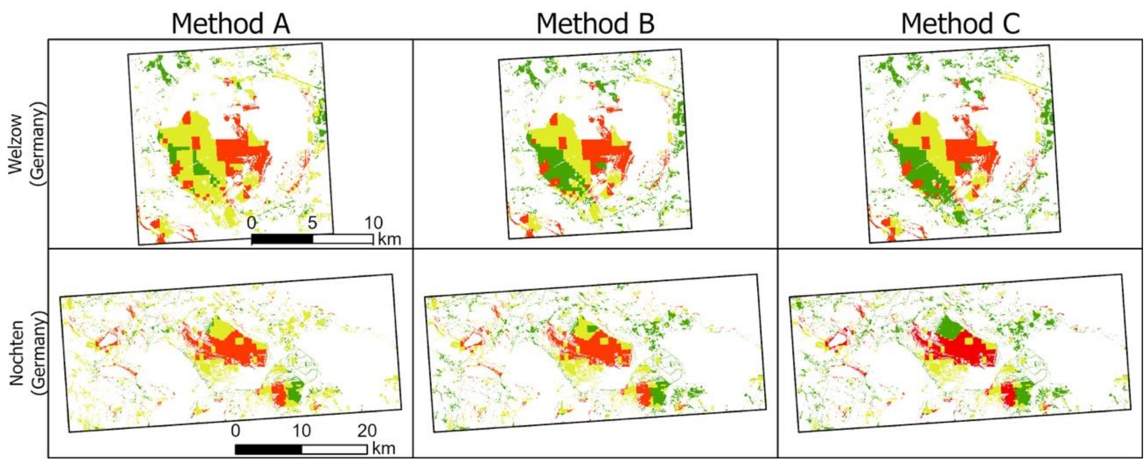

Figure 3: Final Layer of MLs (task 4.1) classified with 3 methods into the 3 categories: "Marginal lands with high plantation suitability" (green), "Marginal lands with low plantation suitability" (yellow) and "Potentially unsuitable lands" (red). Source: Personal compilation of Elisa Bender

Figure 4. Percentage of area classified as ML by typology (ML high, ML low & ML unsuitable) on the pilot sites of Germany. Source: personal compilation of Elisa Bender

As expected, the methodology executed in task 4.1 detects generally less Marginal Lands then task 2.3 (Figure 4). This is because local datasets and more suitable thresholds for Germany were being used, resulting in a more precise layer of hard thresholds.

Especially the detailed layer of protected areas cut out areas that were classified as marginal in task 2.3. Furthermore, the adaptions made to the soft constraints result in very different classifications of Marginal Lands.

In conclusion it can be said that the adapted methodology of 4.1 leads to more meaningful results for Germany and seems reasonable, since all three classification methods of 4.1 show similar results.

3. GREECE

3.1 Site's location

The pilot sites selected in Greece are low productivity lands adjacent to natural parks and forest areas. The test sites are represented in Figure 5. The test sites are two and located in the region of Macedonia and Thrace. One in Thessoloniki prefecture at the mountainous areas above "Thermi" and "Vassilika" and one in Rhodope prefecture and more specifically at the mountainous areas of of "Proskynites" and "Xylagani" southern of Komotini. Part of Thessaloniki's pilot case is "Isenli" forest, where HOMEOTECH had implemented the managerial plan for the period 2007 – 2016. Results and field data from that project were taken into account for better understanding of local marginal lands.

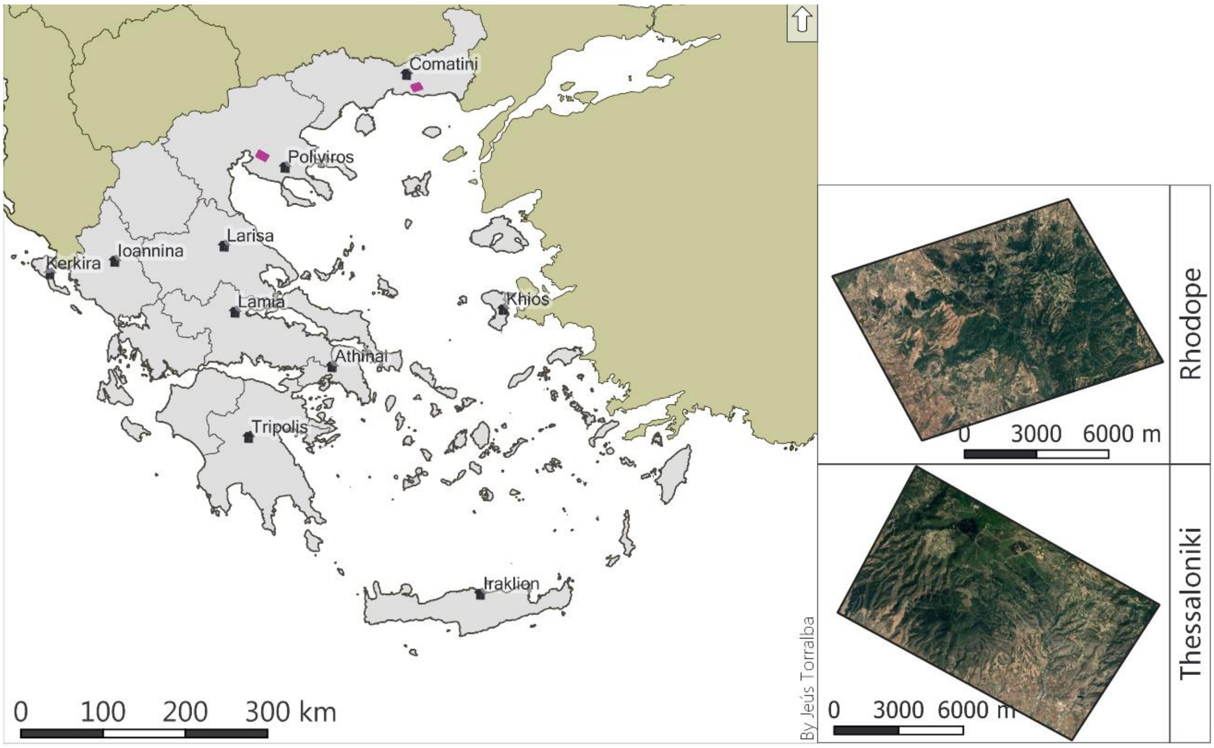

Figure 5. Greece and the pilot site of the afforestation forest of "Rhodope" and "Thessaloniki". Source: personal compilation of Jesús Torralba Pérez.

3.2 Results and comparison

The corresponding areas calculated in hectares of each class for the selected test sites are outlined in Table 4 (areal results of D2.3) and Table 5 (areal results of D4.1).

Table 4. Areas in hectares of each type of MLs for the selected test sites as per derivable 2.3. Source: Personal compilation of Alfonso Abad

Pilot site	Hard layer	Total of ML	Classification Method	ML high	ML low	ML unsuitable
Rhodope (Greece)	Corine Land Cover 2018	2813.42 (35.2%)	min - max	568.90 (7.1%)	1809.54 (22.6%)	434.98 (5.4%)
			p33 – p66	2241.45 (28.0%)	571.97 (7.2%)	0 (0.0%)
			p25 - p75	2024.72 (25.3%)	788.7 (9.9%)	0 (0.0%)
Thessaloniki (Greece)		4631.44 (47.9%)	min - max	2596.92 (26.9%)	1887.25 (19.5%)	147.27 (1.5%)
			p33 – p66	4391.86 (45.5%)	161.48 (1.7%)	78.10 (0.8%)
			p25 - p75	4377.33 (45.3%)	243.57 (2.5%)	10.54 (0.1%)
Total (Greece)		7444.86 (42.2%)	min - max	3165.82 (17.9%)	3696.79 (20.9%)	582.25 (3.3%)
			p33 – p66	6633.31 (37.6%)	733.45 (4.2%)	78.1 (0.4%)
			p25 - p75	6402.05 (36.3%)	1032.27 (5.8%)	10.54 (0.1%)

Table 5. Areas in hectares of each type of MLs for the selected test sites as per derivable 4.1. Source: Personal compilation of Alfonso Abad

Pilot site	Hard layer	Total of ML	Classification Method	ML high	ML low	ML unsuitable
Rhodope (Greece)	Corine Land	561.99 (7.1%)	min - max	453.59 (5.7%)	108.40 (1.4%)	0 (0.0%)

Pilot site	Hard layer	Total of ML	Classification Method	ML high	ML low	ML unsuitable
	Cover 2018		p33 – p66	453.59 (5.7%)	108.34 (1.4%)	0.05 (0.0%)
			p25 - p75	436.54 (5.5%)	125.39 (1.6%)	0.05 (0.0%)
	VEG YPEKA	1523.50 (19.0%)	min - max	1108.96 (13.9%)	227.77 (2.8%)	186.78 (2.3%)
			p33 – p66	1108.96 (13.9%)	227.37 (2.8%)	187.17 (2.3%)
			p25 - p75	1016.70 (12.7%)	320.02 (4.0%)	186.78 (2.3%)
Thessaloniki (Greece)	Corine Land Cover 2018	1.122.78 (11.6%)	min - max	73.97 (0.8%)	1045.89 (10.8%)	2.92 (0.0%)
			p33 – p66	73.97 (0.8%)	255.30 (2.6%)	793.51 (8.2%)
			p25 - p75	72.68 (0.8%)	296.19 (3.1%)	753.91 (7.8%)
	VEG YPEKA	2.409.37 (24.9%)	min - max	328.81 (3.4%)	1210.20 (12.5%)	870.36 (9.0%)
			p33 – p66	328.81 (3.4%)	1098.11 (11.4%)	982.44 (10.2%)
			p25 - p75	327.74 (3.4%)	1237.77 (12.8%)	843.86 (8.7%)
Total (Greece)	Corine Land Cover 2018	1.684.76 (9.5%)	min - max	527.55 (3.0%)	1154.28 (6.5%)	2.92 (0.0%)
			p33 – p66	527.55 (3.0%)	363.64 (2.1%)	793.56 (4.5%)
			p25 - p75	509.21 (2.9%)	421.58 (2.4%)	753.96 (4.3%)
	VEG YPEKA	3.932.87 (22.3%)	min - max	1437.77 (8.1%)	1437.97 (8.1%)	1.057.13 (6.0%)
			p33 – p66	1437.77 (8.1%)	1325.48 (7.5%)	1169.62 (6.6%)

Pilot site	Hard layer	Total of ML	Classification Method	ML high	ML low	ML unsuitable
			p25 - p75	1344.44 (7.6%)	1557.79 (8.8%)	1030.64 (5.8%)

Figure 6 shows the marginal lands for the pilot sites of Greece both as per D2.3 and D4.1. On the graph of Figure 7, are summarized the percentage of area classified as ML for each pilot site of Greece.

For each product and taking into consideration the layer used as hard layer, are compared the methodologies for classification of ML´s that maximize the area classified as marginal on each site. The amount of ML was maximized on the product D2.3 and applying the classification methodology p25 – p75 (42% of the pilot site was set as marginal).

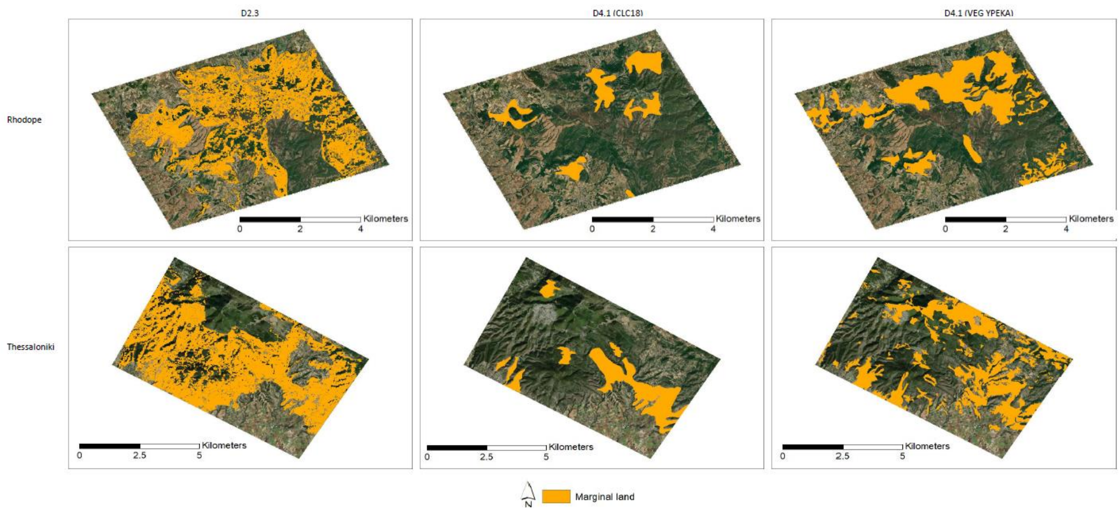

Figure 6. Comparison of ML’s detected as per D2.3 and as per D4.1 (CLC18 and VEG YPEKA as hard layers) for Greece’s pilot sites (Rhodope and Thessaloniki). Source: Personal compilation of Alfonso Abad

The minimum amount of ML was detected on the product D4.1 and using as hard layer CLC18, and classification methodology the min – max option (9.5% of the pilot site was set as marginal).

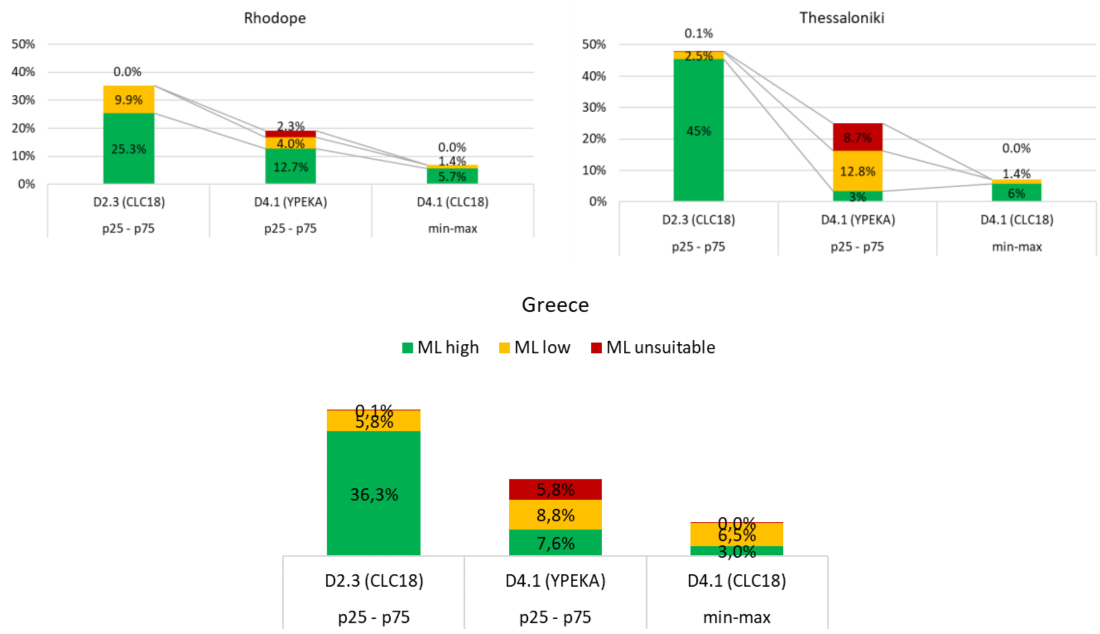

Figure 7. Percentage of area classified as ML by typology (ML high, ML low & ML unsuitable) on the pilot sites of Greece. Source: Personal compilation of Alfonso Abad

The product D4.1 obtained using as hard layer YPEKA classify the 22% of the pilot site as marginal. Regarding the distribution of ML typologies this methodology was found the most equilibrated between ML typologies (ML high, low and unsuitable).

Indisputably both methods detect marginal lands in a very good accuracy. As it was expected a localized system manage to perform better, as it describes sounder the local aspects/particularities. Regarding Greek pilot sites the results obtained on the product D2.3 (42% of the pilot site as marginal) were found excessive considering the local characteristics of the area, as shrubbed areas are considered also marginal.

Regarding the methodology developed in T4.1 for Greece the method using YPEKA as hard layer was found more appropriate to ***MAIL***´s scope in comparison with CLC18 as it seems to describe better the marginality and detect potential lands for future afforestation projects.

4. POLAND

4.1 Site's location

In Poland, the area of one of 16 Voivodeships/Provinces was selected to perform the analyse marginal lands on regional level, using freely available data with higher level of details, comparing to analysis from Task 2.3. Świętokrzyskie Voivodeship covers the area of 11.672 km2 and is cauterized by high number of marginal lands and semi-mountains terrain.

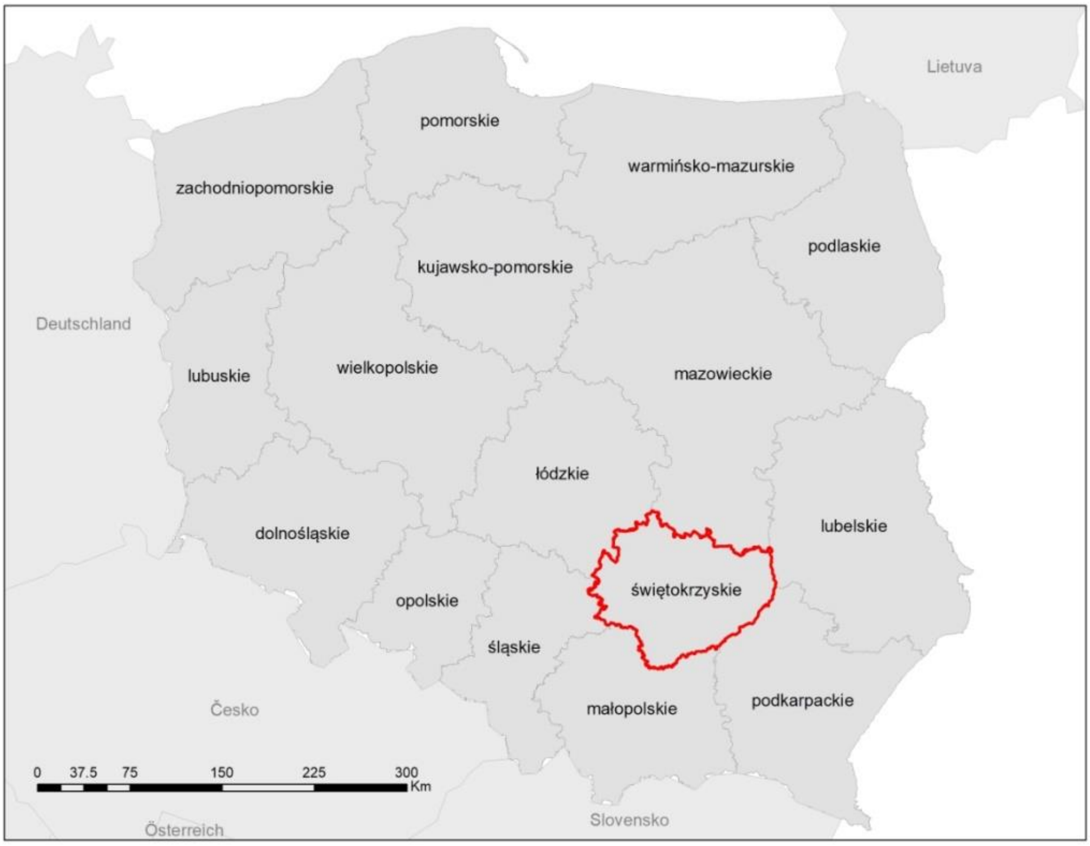

Figure 8. The area of Świętokrzyskie (red line). Source: personal compilation of Ewa Gromny and Michał Krupiński.

4.2 Results and comparison

Division of potential marginal land areas into 3 classes was performed in 3 different ways. The area of specific classes, and their percentage within whole pilot case area are presented in Table 7. For comparison, the results from pan-European layers were extracted and summarized in Table 6.

Table 6: MLs areas for test sites in hectares and percent for each classification method following the 2.3 methodology. Source: Personal compilation of Michał Krupiński

Total of ML	Classification Method	ML high	ML low	ML unsuitable
46345.7 (4.0%)	A: min - max	2807.2 (0.24%)	28392.9 (2.42%)	15145.6 (1.29%)
	B: p25 - p75	11605.6 (0.99%)	22823.3 (1.95%)	11916.8 (1.02%)
	C: p33 – p66	14830.0 (1.27%)	16169.4 (1.38%)	15346.3 (1.31%)

Table 7: MLs areas for test sites in hectares and percent for each classification method following the 4.1 methodology. Source: Personal compilation of Michał Krupiński

Total of ML	Classification Method	ML high	ML low	ML unsuitable
181067.3 (15.5%)	A: min - max	6696.6 (0.57%)	161896.8 (13.82%)	12473.8 (1.07%)
	B: p25 - p75	46013.9 (3.93%)	90599.0 (7.74%)	44454.4 (3.80%)
	C: p33 – p66	62830.4 (5.37%)	64483.2 (5.51%)	53753.7 (4.59%)

To visually compare both methodologies (Task 2.3 and Task 4.1), maps with 3 classes estimated with 3 different methods were prepared and compared (Figure 9).

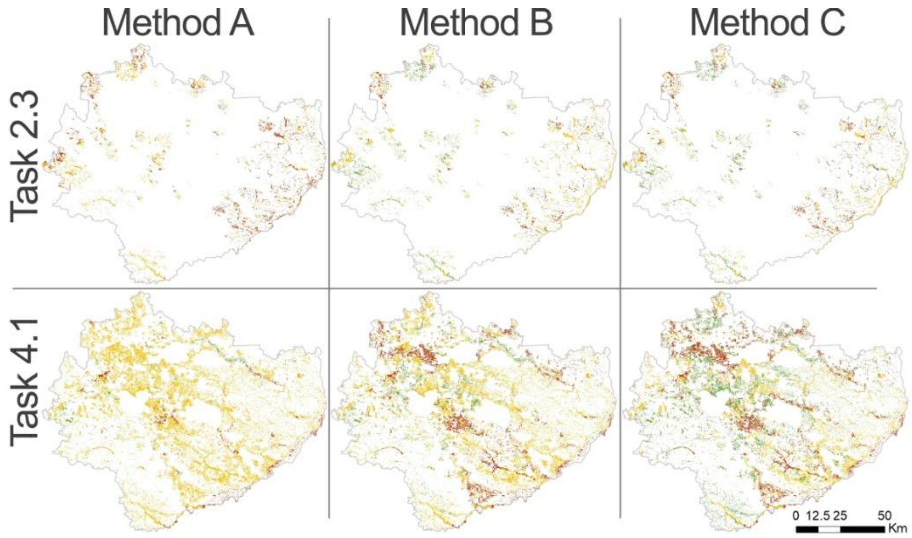

Figure 9. Final Layer of MLs classified with 3 methods into the 3 categories: "Marginal lands with high plantation suitability" (green), "Marginal lands with low plantation suitability" (yellow) and "Potentially unsuitable lands" (red). First row contains result of Task 2.3, second row – Task 4.1. Source: Personal compilation of Michał Krupiński.

Map of marginal lands detected within this task resulted in 3 times more area then in task 2.3 in Polish pilot case, 15.5% of province area, comparing to 4.0%.

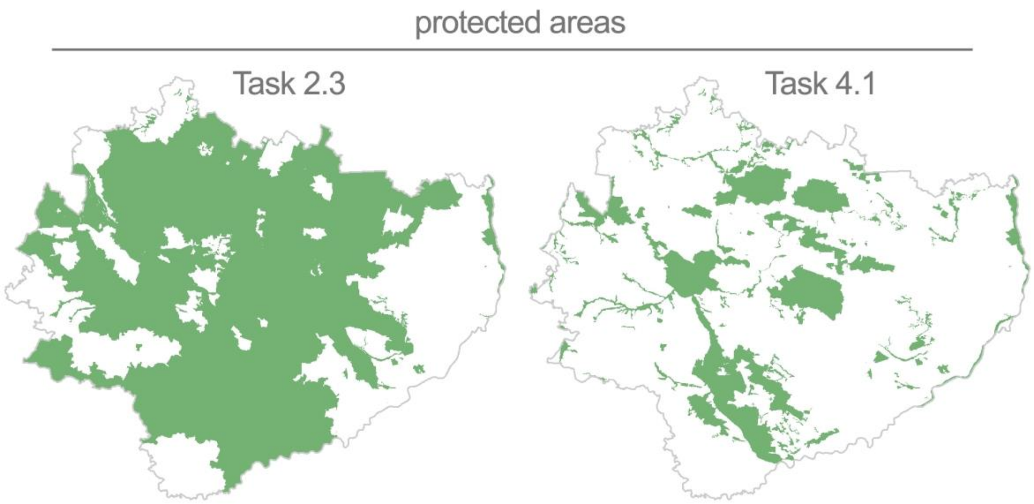

Figure 10. Comparison of Protected areas mask developed within task 2.3 and task 4.1

Detailed comparison of both methodologies, revealed that in Task 2.3 much more protected areas are excluded from analyses (Figure 10). Protected areas in task 2.3

result from combination (sum of areas) of two bases: Natura 2000 and Common Database on Designated Areas (CDDA). CDDA provides more areas than Natura 2000 and in case of Poland it includes regions of protected landscape. This type of protection is defined on province level and does not imply very strict rules about human interventions within. For this reason, this type of protected areas was not applied as hard constrain in Task 4.1.

In the areas outside protected areas defined in Task 2.3, both approaches indicate highly similar results. Comparison of percentage of 3 classes and 2 approaches is presented in Figure 11.

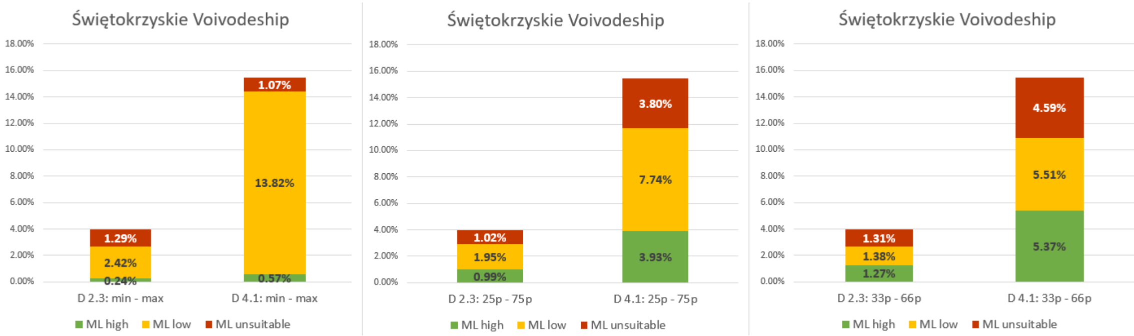

Figure 11. Percentage of area classified as ML by typology (ML high, ML low & ML unsuitable) within pilot case in Poland. Source: Personal compilation of Michał Krupiński.

Besides the method A, two other approaches result in comparable percentage of various marginal land classes. In method A dominates the class of marginal lands with moderate suitability for afforestation.

5. SPAIN

The definition of Marginal Lands in the ***MAIL*** project are lands with significant, either environmental (biophysical variables) or socioeconomic, constraints and with potential to impact national accounting for C stock, excluding agricultural lands and other valuable areas (protected areas, uses with local importance, etc.).

In Mediterranean environments, MLs will be defined to degraded areas and linked to forest fires as vector shaping landscape dynamics.

The selection of indicators for Spain focuses on the detection of land use change dynamics, using the most detailed and up-to-date land cover and land use maps available, capable of identifying changes in the landscape and vegetation formations. However, the model also incorporates socio-economic data restrictions associated to land management at regional/local level. For this reason, the model proposed for Spain develops two levels: the first one integrates a model of indicators for the identification and characterisation of the MLs in the national territory and the second level develops a model for Castile and León, incorporating detailed soft and hard indicators for MLs bounded to that geographic and administrative region.

5.1 Sites location

The methodology based on the definition of two data sets of national and regional indicators is tested in the pilot sites proposed by ***MAIL*** in the national territory: "Tierras Altas" is located in the province of Soria in Castile and León, the area of the Municipality of Nogueruelas (Teruel) in the Central East of the Iberian Peninsula, and the “Sierra de Espadán” in the province of Castellón (region of Valencia), in order to compare the results with the main ***MAIL*** methodology develop at the European level (tasks 2.3, ***MAIL*** Project). These pilot sites were defined as potentially marginal areas and include semi-urban degraded lands and low productivity lands adjacent to natural parks and forest areas.

In the three pilot areas the MLs are analysed and categorised on the basis of the national methodology and compared with the main ***MAIL*** methodology. In addition, the Tierras Altas pilot site allows to compare the three methodologies developed at European, national and regional/local level developing a model for the detection of MLs for Castile and León region and analysing the fit of the models with downscaling

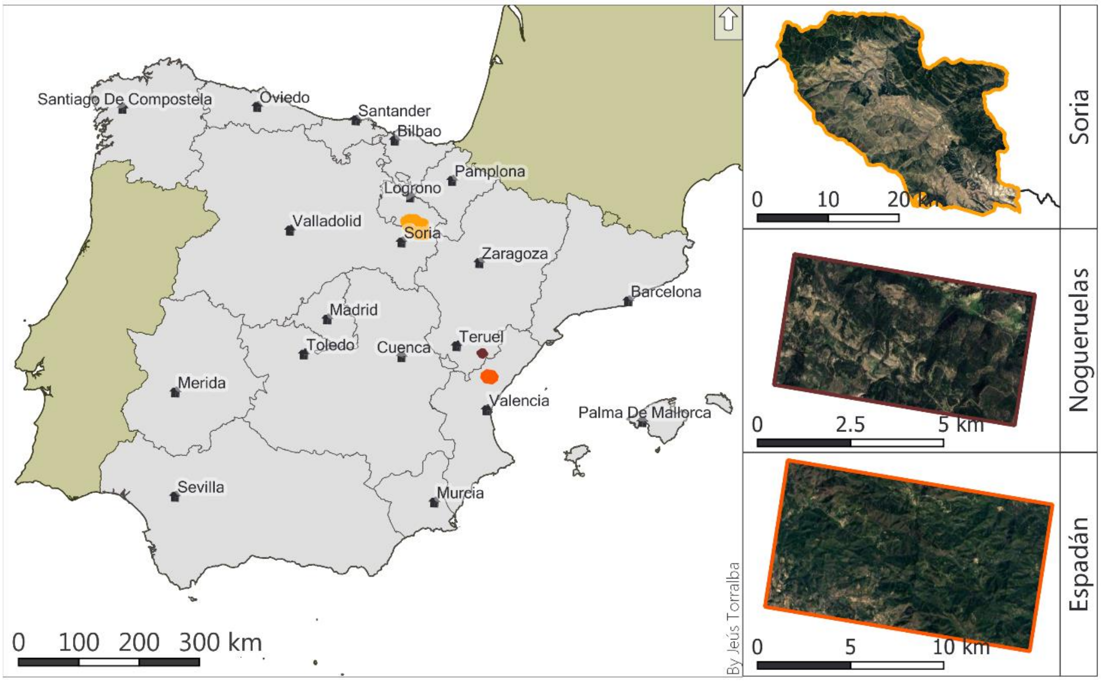

Figure 12:Spain (left) and the pilot site of "Soria" (outlined with light orange), "Nogueruelas" (outlined with dark red), and "Espadán" (right image outlined with dark orange). Source: personal compilation of Jesús Torralba Pérez

5.2 Results and comparison

The objective of this section is to compare the results of the MLS of the different scale models: European, national and regional/local (castile and León), and according to their marginality: "MLs with high plantation suitability", "MLs with low plantation suitability" and "Potentially unsuitable lands" estimated by three methods: a) computing the maximum and minimum and dividing the range of values by 3, b) computing the 25th and 75th percentile and setting these values as threshold limits, c) computing the 33rd and 66th percentile to keep the same number of pixels in each category, to calibrate and validate the uncertainty and sensitivity of each model.

The main ***MAIL*** methodology derived from task 2.3 (Table 8) obtains a lower ML land than the methodology developed for Spain and Castile and León. This is mainly due to the definition of the exclusion (Hard layers) in the main ***MAIL*** methodology, and especially the exclusion of the protected areas of the Natura 2000 network.

Table 8: MLs areas for test sites in hectares and percent for each classification method following the 2.3 methodology. Source: personal compilation of Laura Martín Collado

Pilot site	Total of ML	Classification Method	ML high	ML low	ML unsuitable
Tierras Altas	25719 (26.10)	min - max	3611 (3.66%)	**19194 (19.45%)**	2913 (2.95%)
		p25 - p75	**20367 (20.64%)**	5082 (5.15%)	269 (0.27%)
		p33 – p66	**22587.9 (22.89 %)**	2751.0 (2.79%)	380.5 (0.39%)
Nogueruelas (Teruel)	27.3 (0.8%)	min - max	0 (0%)	12.7 (0.39 %)	**14.6 (0.45 %)**
		p25 - p75	0.3 (0.01 %)	**21.0 (0.65 %)**	6.0 (0.18 %)
		p33 – p66	**12.7 (0.39%)**	8.3 (0.25%)	6.4 (0.20%)
Espadán	623.9 (3.9%)	min - max	0 (0.00%)	**341.8 (2.14%)**	282.0 (1.77%)
		p25 - p75	103.0 (0.64%)	**272.1 (1.70%)**	248.7 (1.56%)
		p33 – p66	341.2 (1.56%)	341.2 (0.21%)	**249.0 (2.14%)**

* The class with the highest value is marked in bold type.

Table 9: MLs areas for test sites in hectares and percent for each classification method following the 4.1 methodology and national level.* Source: personal compilation of Laura Martín Collado

Pilot site	Total of ML	Classification Method	ML high	ML low	ML unsuitable
Tierras Altas	23023 ha (39.92)	min - max	4136 (7.17%)	**12376 (21.45%)**	6512 (11.29%)
		p33 – p66	7899 (13.06%)	5860 (10.16%)	**9264 (16.06%)**
		p25 - p75	6320 (10.95%)	7438 (12.89%)	**9264 (16.06%)**
Nogueruelas (Teruel)	292 ha (12.46%)	min - max	31 (1.33%)	116 (4.92%)	**140 (5.96%)**
		p25 - p75	46 (1.96%)	**183 (7.82%)**	57 (2.44%)
		p33 – p66	78 (3.32%)	100 (4.29%)	**108 (4.60%)**

Pilot site	Total of ML	Classification Method	ML high	ML low	ML unsuitable
Espadán	1376 ha (11.9%)	min - max	207 (1.79%)	**628 (5.43%)**	541 4.67%)
		p25 - p75	203 (1.76%)	462 (4.00%)	**709 (6.1%)**
		p33 – p66	181 (1.56%)	327 (2.83%)	**867 (7.50%)**

* The class with the highest value is marked in bold type.

The improved exclusion of riparian formations and firebreaks from the national model through multi-labelling of the SIOSE mapping as well as the improved classification of forest areas, especially recent forest plantations due to the improved spatial detail and updated information inherent in the national mapping and compared to the Corine Land Cover (CLC) database used in Task 2.3, are noteworthy as shown in Figure 13.

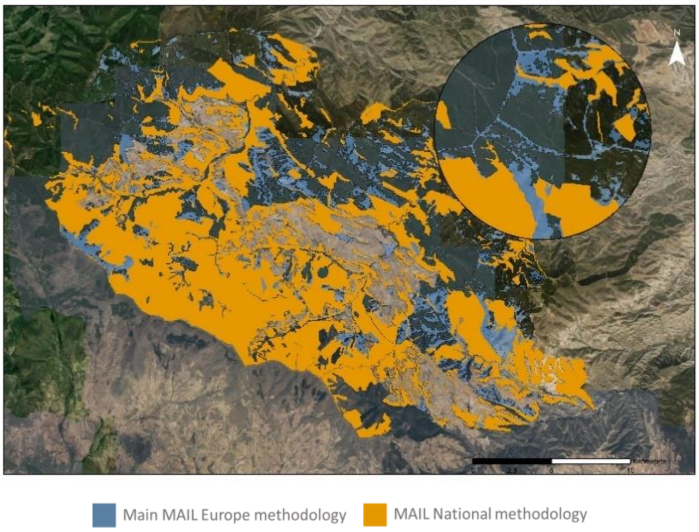

Figure 13: Map of the pilot area "Tierras Altas" (Soria) according to *MAIL* Europe methodology (Blue) and *MAIL* National methology (Orange) zooming in on a forest firebreak area. Source: personal compilation of Laura Martín Collado

The three regional European, national and regional/local models of Castile and León applied in the Tierras Altas pilot site show that marginal areas are a very dynamic phenomenon and depend on the update from the different sources of information available at regional/ local level.

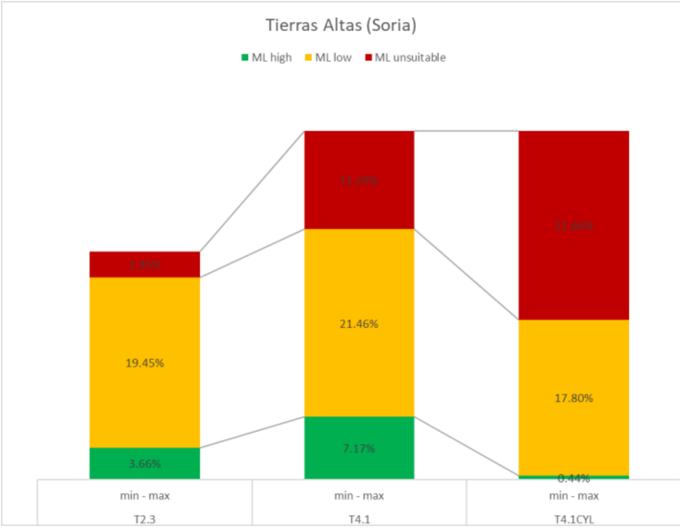

Figure 14: Percentage of area classified by min-max method across the different scale models (Main *MAIL* methodology, 4.1 National Methodology, 4.1 Regional/local methodology) Source: personal compilation of Laura Martín Collado

Regarding the distribution of ML typologies, the national model results the most equilibrated between ML typologies (ML high, low and unsuitable).

The final estimation of the marginal area from the reforestation feasibility point of view is close to the estimates according method A (min-max) of the Castile and León model at 18.4% (ML High + ML Low classes), a smaller area compared to 28.63% in the national methodology and 23.11% in the main ***MAIL*** methodology.

The discrepancy in the estimation of the surface area of the “Potentially unsuitable lands” class between the three scales is remarkable. The regional model of Castile and León estimates a greater area for the unsuitable ML class with a value of 21.66% over compared to the main ***MAIL*** methodology and the national methodology, which obtain values for ML unsuitable of 2.95% and 11.29% respectively (Figure 14).

6. Conclusions

6.1 Germany

The comparison of the results regarding marginal lands from task 2.3 and 4.1 can be summarized as follows: The general methodology from task 2.3 of combining hard thresholds and soft constraints is a reasonable technique for the detection of Marginal Lands. The usage of local data along with thresholds adapted to state laws and regulations is benefitting the site selection process and produces more accurate results. Especially the use of national data for the hard thresholds has a big impact on the outcome, as seen in the case study for Germany.

The methodology used in task 2.3 gives a good overview of potential marginal lands on a Pan-European level. Compared to the adapted methodology of task 4.1 it predicts more marginality because it uses general Pan-European data and thresholds. The methodology used in this case study therefore is more accurate and the results are more precise. Therefore, for further studies on afforestation or reforestation of marginal lands, it is useful to proceed with regional data and adapted methods in order to obtain maximum and realistic results for each individual country.

6.2 Greece

After comparing the MLs detected applying the general methodology (Pan-European level, output of Task 2.3) and the regional modification (Greek level, output of task 4.1), it should be considered as follows:

- The algorithm developed for marginality detection on Task 2.3 can be considered as adequate.
- Applying more detailed dataset as input of the general algorithm improves the detection performance.
- Detail of layers related to vegetation / forest / land coverage description can be considered as a key factor for accuracy improvement.
- Both methods detect marginal lands in a very good accuracy. A localized system manages to perform better, as it describes sounder the local aspects/particularities.
- Methodology developed in T2.3 overestimates marginality for Greece in comparison with the methodology developed in T4.1. This probably happens due to better description of local aspects by the second methodology and by the fact that considers shrubbed areas as transitional forested areas and not as potentially marginal.

- Regarding the methodology developed in T4.1 for Greece the method using YPEKA as hard layer was found more appropriate to ***MAIL***´s scope in comparison with CLC18, as it seems to describe better the marginality and detect potential lands for future afforestation projects.

6.3 Poland

Adjustment of pan European methodology to local conditions within Polish pilot was performed on province level and can be up scaled to the national level. Availability of land cover / land use data with high level of details, available in open access allows for precise detection of potential marginal lands (hard layer). National Database of Topographic Objects BDOT 10k was used to provide exclusion mask.

Access to open access, digital, georeferenced data about soil properties revealed issues like: lack of soil properties which are available on European level (e.g., about texture, erosion, socidity, contamination, etc.), lack of full data coverage.

Comparing to European approach (Task 2.3), regional methodology identified 3 times more potential marginal lands. It can result from detailed class definitions within national database, comparing to classes used in Task 2.3.

6.4 Spain

The comparison of the three models for the detection and classification of marginal areas with the main ***MAIL*** methodology, the model for Spain and the model for Castile and León shows that dynamics and variability are key concepts for the identification of marginal lands. In this respect it is significant the application of the appropriate threshold of tree cover values according to the national forest definition, instead of the common value of 30%.

By way of summary, the following points should be considered for downscaling the main ***MAIL*** methodology at national and regional/local level to improve the accuracy of the detection of MLs:

<u>On national level:</u>

- The methodology used in task 2.3 gives a good overview of potential marginal lands on a Pan-European level and by keeping the methodology scheme, it is possible to adapt the model according to the availability of information and to implement local datasets.

- Especially the use of national data for the hard thresholds improves the detection of MLs. In this aspect, the national model proposes not to create a mask with protected areas and to analyse these areas on a regional level.
- The national model incorporates updated and detailed land use and land cover information through SIOSE mapping that improves the description of forest and shrubland area useful for the detection of marginal areas and their characterisation.
- The use of SIOSE labelling achieves model fit in areas of scrub or sparse woodland excluding riparian protection functions and forest firebreaks.

On regional/local level:

- The usage of local data along with thresholds adapted to state laws and regulations is benefitting the site selection process and produces more accurate results.
- The application of regional information related to regional regulations adjusts the detection of MLs and improves the weighting of the level of marginality with the biophysical characteristics of the region.
- Improving understanding of complex socio-ecological systems and developing eco-social indicators is key for the detection of MLs at local level.

REFERENCES

[1] Basak, S. (2006). Landfill site selection by using geographic information systems. Environmental Geology, *49*, 376-388.

[2] Eckelmann, W., Sponagel, H., Grottenthaler, W., Hartmann, K. J., Hartwich, R., Janetzko, P., ... & Traidl, R. (2006). Bodenkundliche Kartieranleitung. KA5.

[3] Goepel, K. D. (2019). Comparison of Judgment Scales of the Analytical Hierarchy Process - A New Approach. International Journal of Information Technology and Decision Making, 18(2), 445–463. https://doi.org/10.1142/S0219622019500044

[4] Mueller, L., Schindler, U., Behrendt, A., Eulenstein, F., & Dannowski, R. (2007). The Muencheberg soil quality rating (SQR).

[5] Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. European Journal of Operational Research, 48(1), 9–26. https://doi.org/10.1016/0377-2217(90)90057-I

[6] Saaty, T. L., & Vargas, L. G. (2001). Models, methods, concepts & applications of the Analytic Hierarchy Process. Springer Science+Business Media, LLC. https://doi.org/10.1057/jors.1962.41

[7] Siraj, S. (2011). Preference Elicitation from Pairwise Comparisons for Traceable Multi-Criteria Decision Making.

[8] Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. European Journal of Operational Research, 169(1), 1–29. https://doi.org/10.1016/j.ejor.2004.04.028

[9] Visser, H., & De Nijs, T. (2006). The map comparison kit. Environmental Modelling and Software, 21(3), {Bibliography}346–358. https://doi.org/10.1016/j.envsoft.2004.11.013

[10] Area notebooks for the implementation of afforestation works on agricultural land (2014-2020). Junta de Castilla y León. Retrieved November 15, 2021, from https://medioambiente.jcyl.es/

[11] Ciria, Carlos & Sanz, Marina & Carrasco, Juan & Ciria, Pilar. (2019). Identification of Arable Marginal Lands under Rainfed Conditions for Bioenergy Purposes in Spain. Sustainability. 11. 1833. 10.3390/su11071833.

[12] Cortina, Jordi & Amat, Beatriz & Castillo, V. & Fuentes, David & Maestre, Fernando & Padilla, Francisco & Rojo, L. (2011). The restoration of vegetation cover in the semi-arid Iberian southeast. Journal of Arid Environments. 75. 1377-1384. 10.1016/j.jaridenv.2011.08.003.

[13] Meier, E.S.; Indermaur, A.; Ginzler, C.; Psomas, A. An Effective Way to Map Land-Use Intensity with a High Spatial Resolution Based on Habitat Type and Environmental Data. Remote Sens. 2020, 12, 969. https://doi.org/10.3390/rs12060969

[14] Spanish Land Cover / Land Use. Information System. - SIOSE2005 -. National Geographic Institute of Spain. Gobierno de España. Ministerio De Fomento. Retrieved November 10, 2021, from https://www.ine.es

[15] Vilagrosa, Alberto & Caturla, RN & Hernández, N & Cortina, Jordi & Bellot, Juan & Vallejo, Ramon. (2001). Reforestación en ambiente semiárido del sureste peninsular. Resultados de las investigaciones desarrolladas para optimizar la supervivencia y el crecimiento de especies autóctonas. Montes para la sociedad del nuevo milenio. III Congreso Forestal Español. Junta de Andalucia-Consejeria de Medio Ambiente. 4. 5.

ANNEX I: TABLE OF FIGURES

ANNEX II: LIST OF TABLES