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Web INTEractive management tool for coal Regions in transition

WINTER

Deliverable 2.3

Report on spatiotemporal evaluation and transition scenarios for the coal mining regions

Public Report

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EXECUTIVE SUMMARY

This report is the first part of the Deliverable 2.3 of the WINTER project. It focuses on evaluating the spatiotemporal aspects of coal mining regions. Specifically, it looks at changes in land cover and urban planning in Western Macedonia in Greece, Konin region in Poland, and the Ruhr area in Germany. This evaluation is based on the analysis of satellite and aerial photographs from 1990 to 2021. A significant part of this analysis involves using Copernicus Land Cover datasets and Sentinel-2 satellite multispectral images, particularly from 2018 to 2021. For this recent period, a machine learning algorithm was applied to classify and identify trends in land cover within and around Greek and Polish coal/lignite mines.

The second part of the report discusses the potential for reusing these mining areas for renewable energy, specifically wind and solar power. This part of the analysis takes into consideration the current national legislations in Greece and Poland, providing a framework for understanding how these regions can transition from coal mining to renewable energy generation. The analysis is critical in identifying suitable locations for wind and solar farms and understanding the legislative and environmental implications of such a transition.

The findings from these analyses are essential for the second part of the Deliverable 2.3. They provide valuable data for the preparation of transition scenarios. These scenarios are crucial for planning the future of these regions, guiding decisions on land use, and helping to shape policies for sustainable development. The report's comprehensive approach in analyzing land cover changes and exploring renewable energy options offers a forward-looking plan for transitioning coal mining regions towards a more sustainable and environmentally friendly future.

PROJECT OVERVIEW

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TECHNICAL GROUP:	TGK 1
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TITLE:	**Web INTEractive management tool for coal Regions in transition**
ACRONYM	**WINTER**
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START DATE:	01/07/2022
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ON SCHEDULE (*YES /NO)*:	Yes
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CORRECTION – ACTIONS:	None
PUBLICATIONS, PATENTS:	None

PART I
SPATIOTEMPORAL EVALUATION

1. SPATIOTEMPORAL EVALUATION OF SATELLITE AND AERIAL PHOTOS TO DETECT CHANGES IN SPATIAL AND URBAN PLANNING FOR THE SELECTED REGIONS

This work outlines the data and methodology used for the selected regions and open-pit mines in Western Macedonia-Greece (Amynteo & Ptolemaida), Koning region-Poland (Kazimierz, Jóźwin, and Adamów), and the Ruhr area in Germany, combining Geographical Information System (GIS) and Remote Sensing (RS) techniques as long as open-source datasets. Initial objective was to identify and quantify the spatiotemporal evolution of Land Cover (LC) categories within the boundaries of the studied areas and their regional surroundings from 1990 to 2018 in regional level. Specifically, for the three regions, Copernicus Land Cover datasets from 1990 to 2018 were gathered, and Sentinel-2 satellite multispectral images from 2018 to 2021. Especially for the time period from 2018 to 2021, a Machine Learning (ML) algorithm was implemented in an effort to classify and identify the spatiotemporal evolution trend within the boundaries of the selected Greek and Polish coal/lignite mines as described in the following text.

1.1. DATA SPECIFICATION

Sentinel-2

The SENTINEL-2 is a European satellite mission from the Copernicus Programme which is a constellation with two polar-orbiting satellites (Sentinel-2A and Sentinel-2B) phased at 180° to each other, in a sun-synchronous orbit. The satellites are designed to give a high revisit frequency of 10 days at the Equator (one image per 5 days, while operating together) at a mean altitude of 786 km above the earth surface. SENTINEL-2 carries an optical instrument its wide swath width is 290 km that samples 13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution.

Corine Land Cover (CLC)

Corine Land Cover (CLC) is an inventory of standardized data collection of the Copernicus Land Monitoring Service (CLMS) that provides geographical information related to land cover/ land use and its changes in Europe to support environmental policy development. It consists of 44 land cover classes with a Minimum Mapping Unit of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. The CLC datasets started in 1985 with reference year on 1990 and since then, four updates have been produced for 2000, 2006, 2012, and 2018 (Copernicus Land Monitoring Service).

Dataset preparation & specifications

Coordinate system

It is well known that every geospatial data set is displayed using a geographic or projected coordinate system. All the datasets were projected and processed locally, into ETRS LAEA in order to be comparable on a European scale. Particularly, all geospatial data were transformed and/or produced in the Lambert Azimuthal Equal Area (LAEA) ETRS_1989 with WKID: 3035 Authority: EPSG.

The final products were re-projected into WGS_1984_Web_Mercator_Auxiliary_Sphere in order to be properly displayed on the WebGIS platform. Although, calculations related to geometrical properties such as area coverage and distances were based on ETRS_1989_LAEA.

Study area boundaries

Regarding the regional level for Greece, Poland and Germany (Figure 1) and the time period from 1990 to 2018 boundaries were defined based on existing sources from Eurostat. On the other hand, the polygon limits for the ML approach were defined by utilizing CLC 2018 as a baseline, regarding the CLC primary class titled as mineral extraction sites and Industrial areas. Additionally, the boundaries were edited by combining and digitizing Sentinel-2 image acquisitions obtained in September 2021. The resulting shapefiles (vectors, polygon geometry) were used as Areas of Interest (AOIs) to isolate the satellite images for the implementation of the ML algorithm. The total extent of the selected AOIs is presented with yellow colour in Figure 2 and Figure 3, respectively.

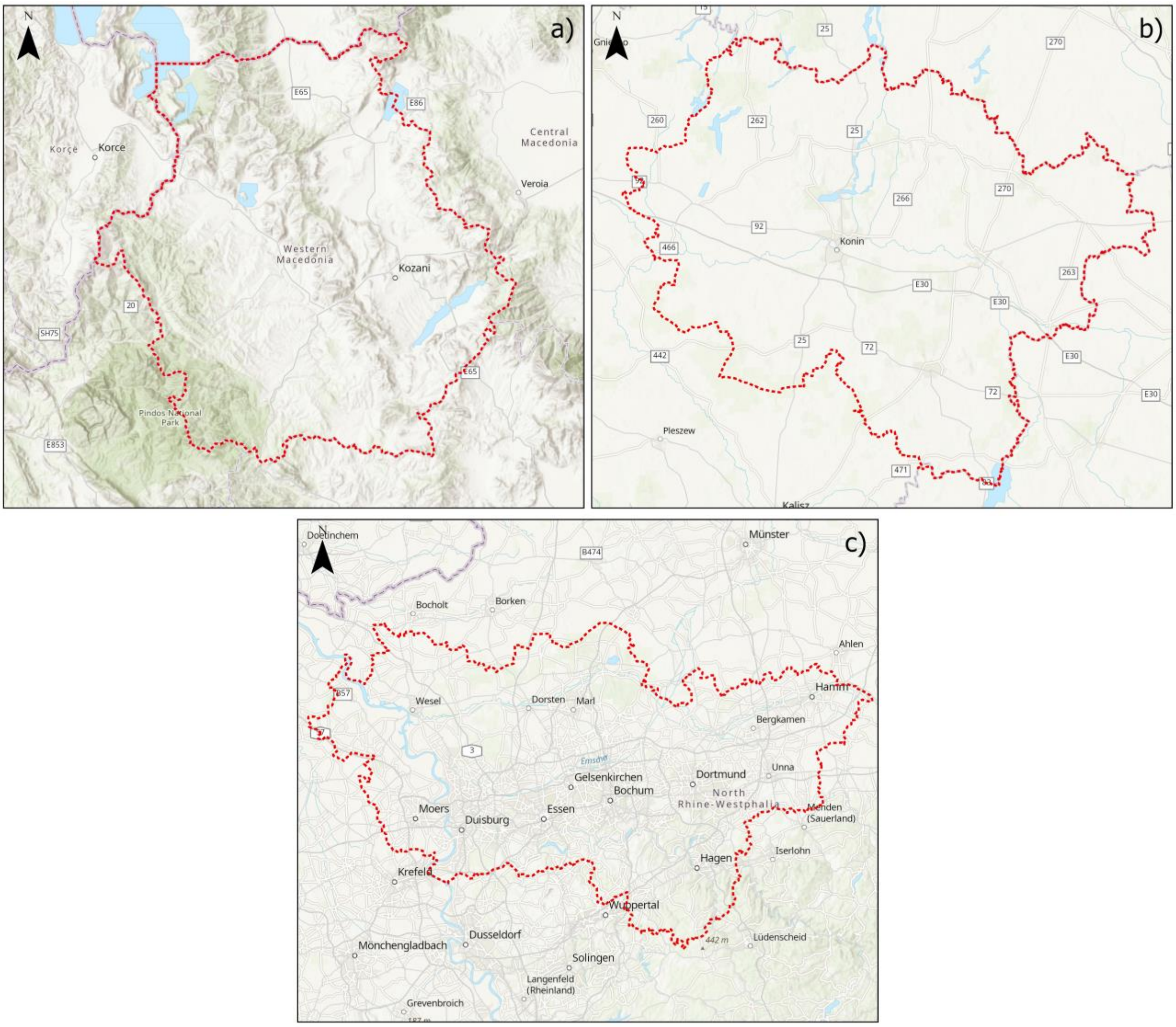

Figure 1. Regional boundaries of the three regions a) Western Macedonia (Greece), b) Konin (Poland), c) Ruhr area (Germany)

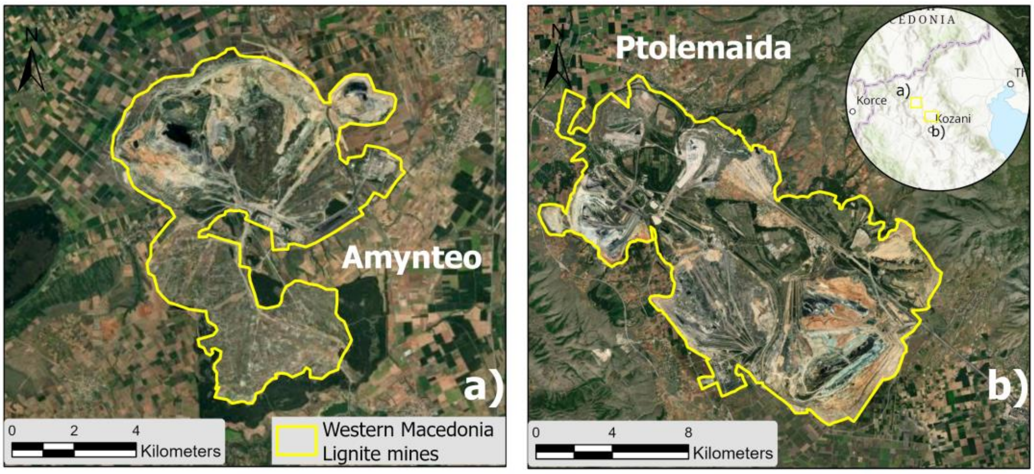

Figure 2. Greek case studies boundaries

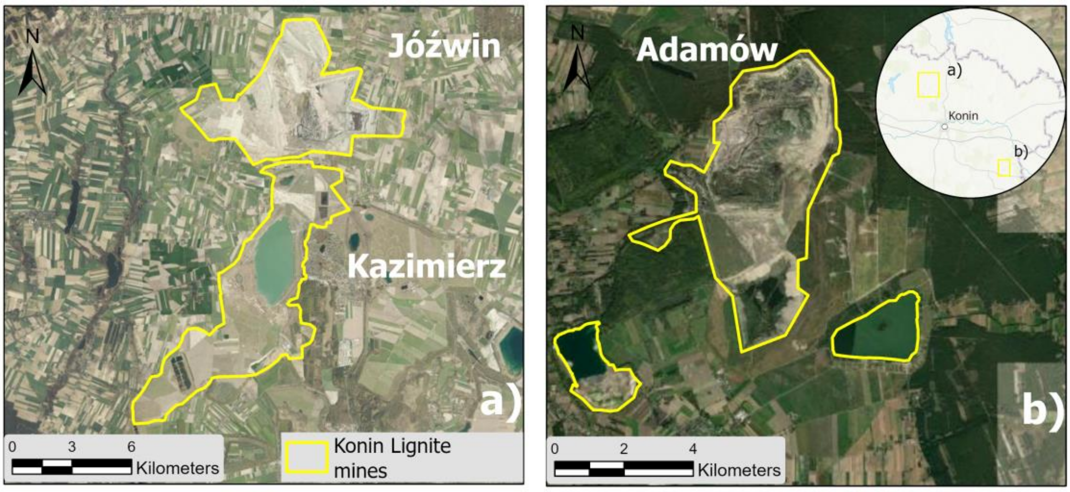

Figure 3. Polish case studies boundaries

1.2. METHODOLOGY

Spatiotemporal evaluation based on Corine Land Cover products

The Corine Land Cover (CLC) approach was applied for the wider area of the three regions (Western Macedonia, Konin, Ruhr) during the time period 1990 to 2018. To optimize visualization and to better understand the spatiotemporal evolution, Level 2 types of LC were merged into Level 1 category, excluding Marine Waters and Coastal Wetlands for each reference year. From this perspective, the main class “Artificial surfaces”, was divided into three sub-categories (Table 2) in order to investigate the evolution of urban fabric, the industrial and mine sites, separately. Particularly, the statistical analysis was based on the spatial extent of each class during the 1990 to 2018 by quantifying their areal changes in terms of relative percentages values.

Table 1. Corine Land Cover nomenclature modified by (Heymann et al., 1994)

Level 1 (Main classes)	Level 2 (LC types)	Level 3 (Classes)
1. ARTIFICIAL SURFACES	1.1 Urban fabric	1.1.1 Continuous urban fabric
		1.1.2 Discontinuous urban fabric
	1.2 Industrial, commercial and transport units	1.2.1 Industrial or commercial units
		1.2.2 Road and rail networks and associated land
		1.2.3 Port areas
		1.2.4 Airports
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites
		1.3.2 Dump sites
		1.3.3 Construction sites
	1.4 Artificial, non-agricultural vegetated areas	1.4.1 Green urban areas
		1.4.2 Sport and leisure facilities
2. AGRICULTURAL AREAS	2.1 Arable land	2.1.1 Non-irrigated arable land
		2.1.2 Permanently irrigated land
		2.1.3 Rice fields
	2.2 Permanent crops	2.2.1 Vineyards
		2.2.2 Fruit trees and berry plantations
		2.2.3 Olive groves
	2.3 Pastures	2.3.1 Pastures
	2.4 Heterogeneous agricultural areas	2.4.1 Annual crops associated with permanent crops
		2.4.2 Complex cultivation patterns
		2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation

Level 1 (Main classes)	Level 2 (LC types)	Level 3 (Classes)
		2.4.4 Agro-forestry areas
3. FOREST AND SEMI NATURAL AREAS	3.1 Forests	3.1.1 Broad-leaved forest
		3.1.2 Coniferous forest
		3.1.3 Mixed forest
	3.2 Scrub and/or herbaceous vegetation associations	3.2.1 Natural grasslands
		3.2.2 Moors and heathland
		3.2.3 Sclerophyllous vegetation
		3.2.4 Transitional woodland-shrub
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, sands
		3.3.2 Bare rocks
		3.3.3 Sparsely vegetated areas
		3.3.4 Burnt areas
		3.3.5 Glaciers and perpetual snow
4. WETLANDS	4.1 Inland wetlands	4.1.1 Inland marshes
		4.1.2 Peat bogs
	4.2 Maritime wetlands	4.2.1 Salt marshes
		4.2.2 Salines
		4.2.3 Intertidal flats
5. WATER BODIES	5.1 Inland waters	5.1.1 Water courses
		5.1.2 Water bodies
	5.2 Marine waters	5.2.1 Coastal lagoons
		5.2.2 Estuaries
		5.2.3 Sea and ocean

Table 2. Artificial surface division for statistical analysis

	Sub-categories	LC type
Artificial surfaces	Urban fabric	Urban fabric
		Artificial, non-agricultural vegetated areas
	Mine, dump and construction sites	Mine, dump and construction sites

	Industrial, commercial and transport units	Industrial, commercial and transport units

Spatiotemporal evaluation based on Machine Learning products

In general, the methodology of this subtask was separated into three-fold processing: 1) the development of a geodatabase importing and homogenizing geospatial datasets; 2) the training and implementation of Machine Learning (ML) algorithm; and 3) the identification and quantification of LC within the boundaries of the two case studies, in an effort to evaluate the green transition and create an output for the next subtask (2.3.2) adopting a ML approach (Krassakis et al., 2022).

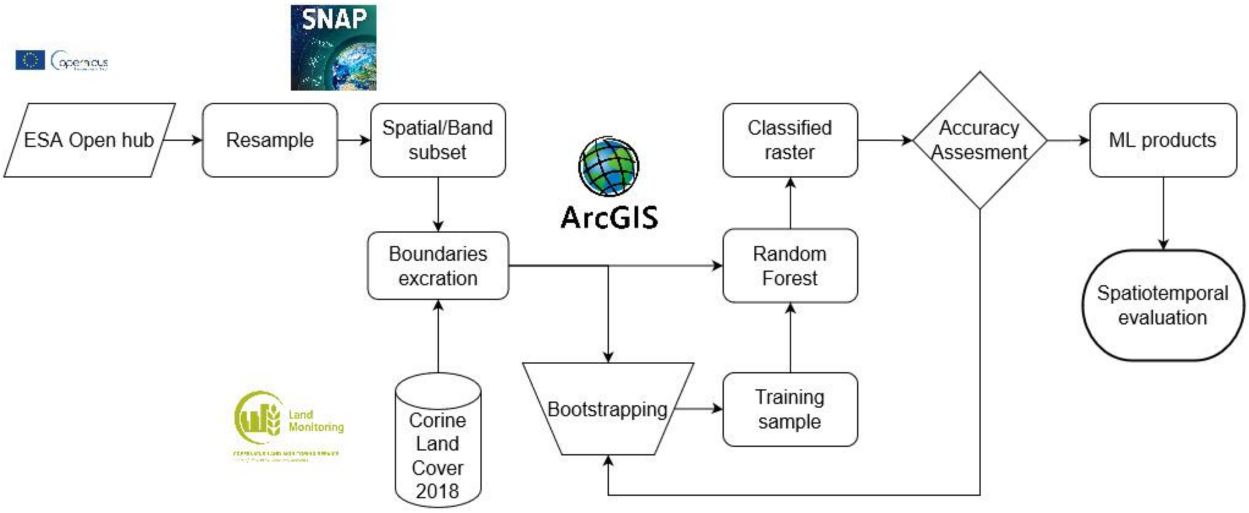

Figure 4. Schematic Workflow

According to the upper and left part of the workflow (Figure 4), the first step was the pre-processing phase of satellite images using the free software Sentinel Application Platform (SNAP) provided by the European Space Agency (ESA). Regarding the presented workflow (Figure 4) and the middle-center part of it, the images were clipped into specific boundaries of the mining open-pits in order to focus in the specific characteristics of the study areas. In particular, the boundaries were determined based on CLC 2018 classes titled as Mineral extraction sites (code: 131) and as Industrial or commercial units (code: 121) which are close to the open-pits.

Following the schematic workflow (Figure 4), the next step was the training process phase of the machine learning algorithm to identify the land cover types within the boundaries of the study areas. The ML technique used for this process was Random Forest (RF) (Breiman et al., 2001). For the purposes of the WINTER Project, five classes were identified in order to categorize the land cover types within the boundaries of the open-pits.

These classes are presented and described in Table 3. Lastly, the generated ML products were statistically analyzed in order to evaluate the spatiotemporal evolution.

Table 3. Selected Land cover categories for the implementation

Class		Color
Bare soil	An adequate water supply is essential for cultivation and the growth of aquatic crops. Additionally, the term 'bare surface' refers to land that is exposed and/or has sparse vegetation.	(Brown)
Infrastructures	Characterized by open pit mining facilities, cement and dirt road network.	(Red)
Mining active area	Characterized by surface mining processing, highly reflective rubble and dumping ground.	(Purple)
Vegetation	Includes timber stands, forests, and shelterbelts that have high chlorophyll content, shrub forest having multiple stems and shorter height.	(Green)
Water bodies	Characterized by surface covered by water (e.g., pit-lakes).	(Blue)

1.3. RESULTS

In this section the results of the applied geospatial analysis as well as the visualization of maps are presented. In addition, the statistical analysis based on the coverage percentage of every class in terms of relative changes. Particularly, absolute change is the direct measure of the quantitative change in the land cover over time. It reflects the actual increase or decrease in the land cover category's area. For instance, if a mine area decreased from 150 km2 in 1990 to 130 km2 in 2018, the absolute change would be a reduction of 20 km2 in mine cover. On the other hand, relative change is a measure that expresses the absolute change as a proportion or percentage of the second period. For example, if the total mine area is reduced by 20 km2 from 1990 to 2018, then the relative change would be a (20*100)/130 = 15.4% decrease in mine cover relative to the second period.

WESTERN MACEDONIA REGION

Corine Land Cover spatiotemporal analysis

Based on the quantification of CLC products (Figure 5) in the Western Macedonia region, an evaluation of spatiotemporal changes was conducted for all main classes during the period from 1990 to 2018. In particular, in terms of relative change (Table 4), the percentage of agricultural areas decreased by up to 7.03%, while the urban sub-categories (Industrial, Commercial, and Transport Units; Mines, Dumps, and Construction Sites; Urban Fabric) increased by a total of

101.35%. Additionally, forest and semi-natural areas faced an increase of up to 1.98%, and water bodies by 3.64%, whereas wetlands decreased by 19.31%. Among the three sub-categories of artificial surfaces, the Industrial, Commercial, and Transport Units underwent the most significant expansion, indicating the growth of industrial and mining activities in the Western Macedonia region the particular time period. It is worth to be mentioned that the Mines, Dumps, and Construction Sites category depicted an increase up to 170%.

Table 4. Statistical analysis of the LU/LC coverage in Western Macedonia region

Class/Year	1990	2000	2006	2012	2018	Relative (%) change
Industrial, commercial and transport units	0.22	0.31	0.45	0.61	0.66	196.05
Mine, dump and construction sites	0.54	1.14	1.28	1.31	1.45	170.06
Urban fabric	0.78	0.79	0.94	0.98	0.98	26.51
Agricultural Areas	37.74	37.21	36.79	35.28	35.09	-7.03
Forest and seminatural areas	57.95	57.94	57.96	59.23	59.10	1.98
Wetlands	0.25	0.24	0.15	0.22	0.20	-19.31
Water bodies	2.43	2.36	2.44	2.37	2.52	3.64

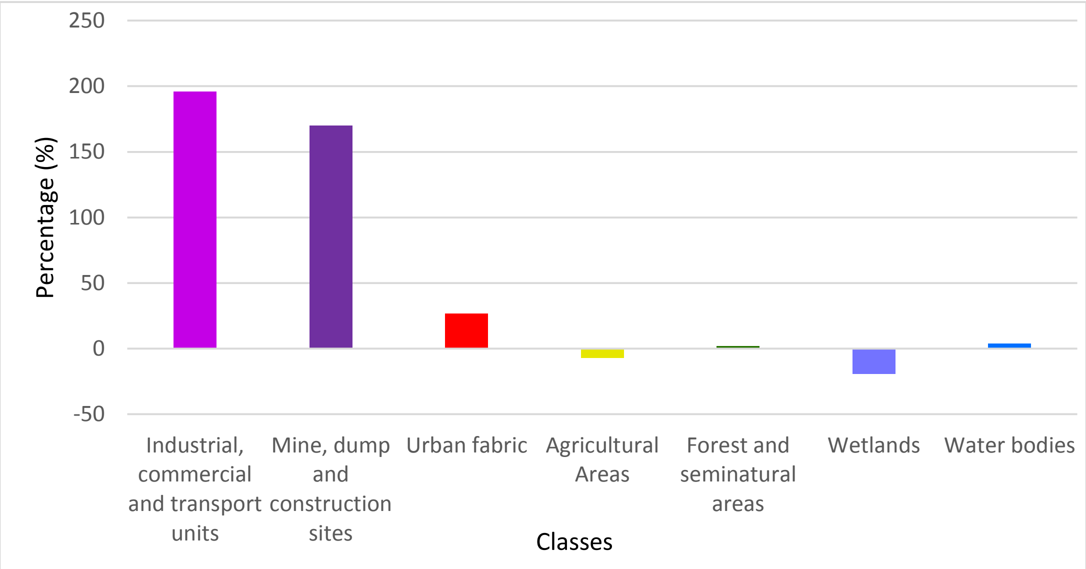

Figure 5. Relative change of LC/LU types in Western Macedonia region, during the time during the 1990 to 2018. The violet color presents the “Industrial, commercial and transport units”, the purple color depicts “Mine, dump and construction sites” , the red color represents the “Urban fabric”, the yellow color depicts the “Agricultural areas”, the green color illustrates the “Forest and seminatural areas”, the blue color presents the “Wetlands” and dark blue color represents the “Water bodies”.

Additionally, by comparing the spatial patterns within the Western Macedonia region boundaries (Figure 6), it is clear that the most significant urban expansion is concentrated around the city of

Ptolemaida (Figure 7). This expansion can be attributed to the urbanization of cities and settlements, due to the parallel historical development of the Amynteo and Ptolemaida mines from 1990 and after.

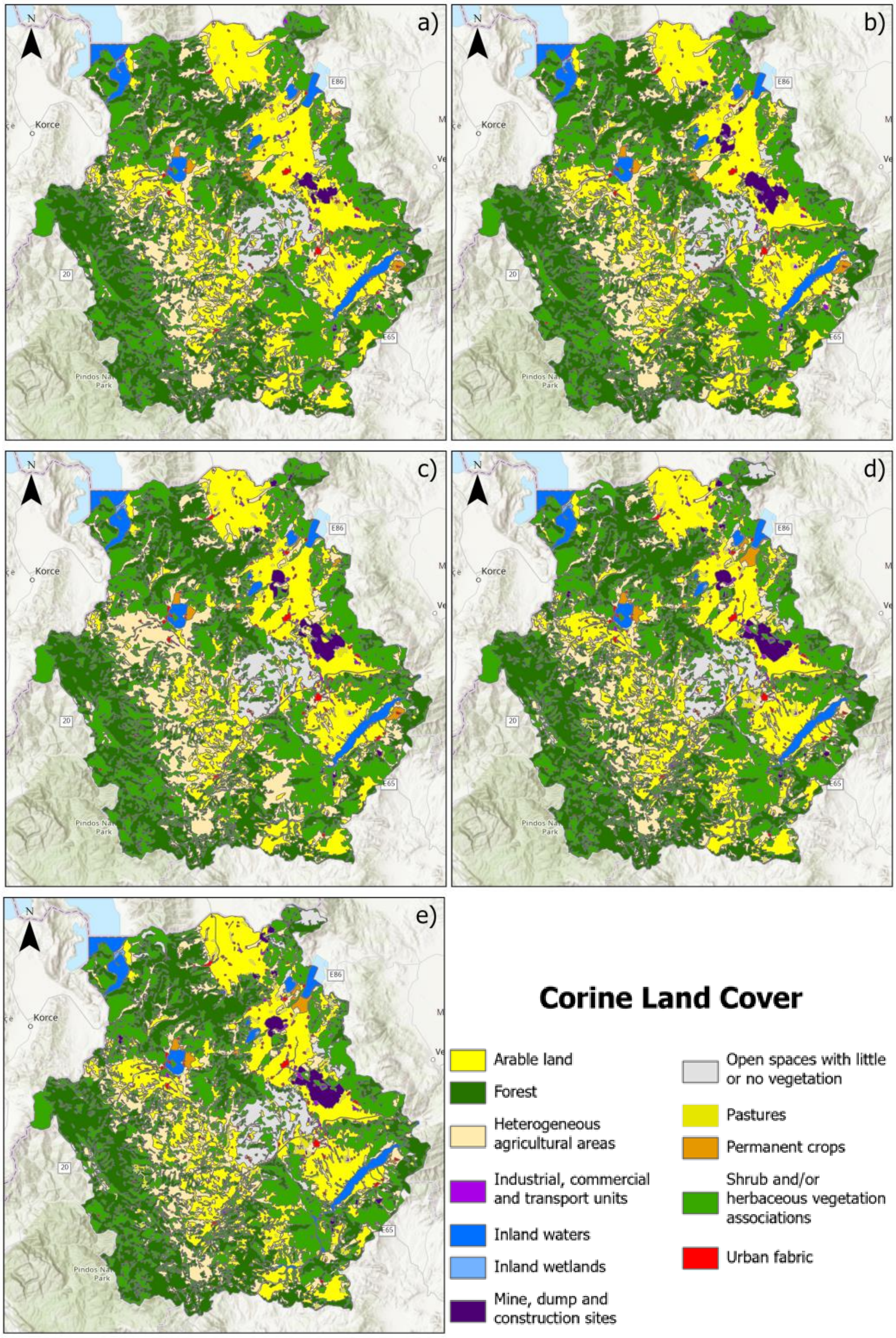

Figure 6. Corine Land Cover maps of Western Macedonia region during the time period a)1990, b) 2000, c) 2006, d) 2012, e) 2018. The yellow color represents “arable land”, dark green color depicts “Forest”, beige color illustrates “heterogeneous agricultural

areas", purple color presents "industrial, commercial and transport units", dark blue color illustrates "inland water", light blue color depicts "inland wetlands", dark purple color presents "mine, dump and construction sites", grey color represents "open spaces with little or no vegetation", fade yellow(?) color depicts "pastures", orange color presents "permanent crops", green color depicts "shrub and/or herbaceous vegetation associations" and red color illustrates "urban fabric".

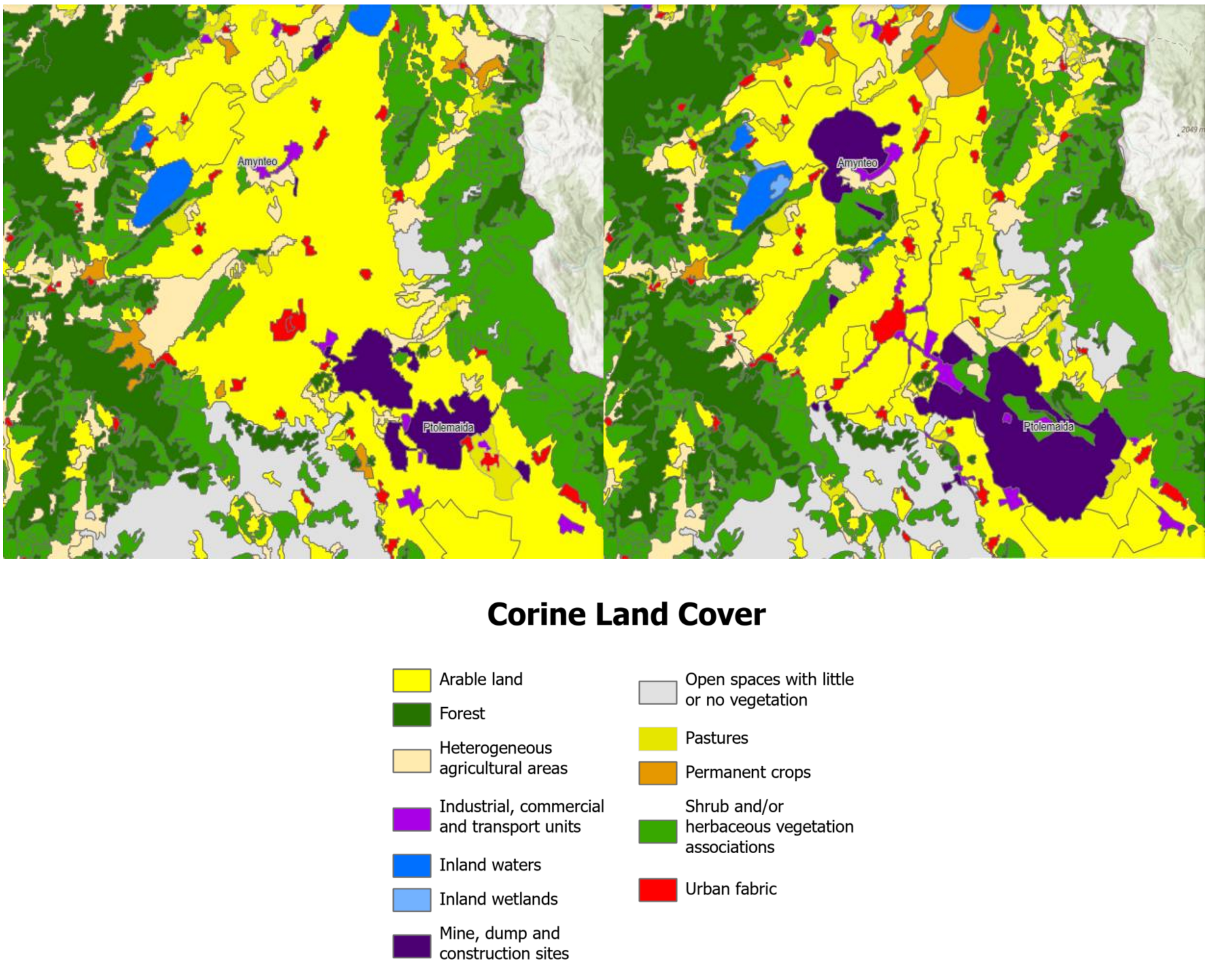

Figure 7. Comparison of LU/LC changes between the 1990 (left) and 2018 (right) in the wider area close to Ptolemaida and Amynteo open-pit mines

Amynteo

According to subtask 2.3.1, and the ML analysis within the boundaries of the mines, the quantified results (Table 5) were obtained from the Amynteo open-pit, illustrating a trend toward green transition for the period from 2018 to 2021 (Figure 8). Specifically, the relative change in the percentage of active mining areas (depicted in purple) depicted a decrease up to 45%, while the bare soil class has increased by 111.14%.

In an effort to better understand the transition of the mining pit, the land cover classes of bare soil, vegetation, and water bodies were merged into a unified class titled as 'Green Transition' (Figure 9) and then were compared with the calculated extent of the ML algorithm. Additionally, Figures 8c and 8d illustrate a clear increase in water bodies (shown in blue) in the northwestern part of the Amynteo pit, as a results of an ongoing development of an artificial pit lake in the 2021 (Figure 8d).

As mentioned in the previous section, bare soil is represented in brown, infrastructures in red, mining active areas in purple, vegetation in green, and water bodies in blue.

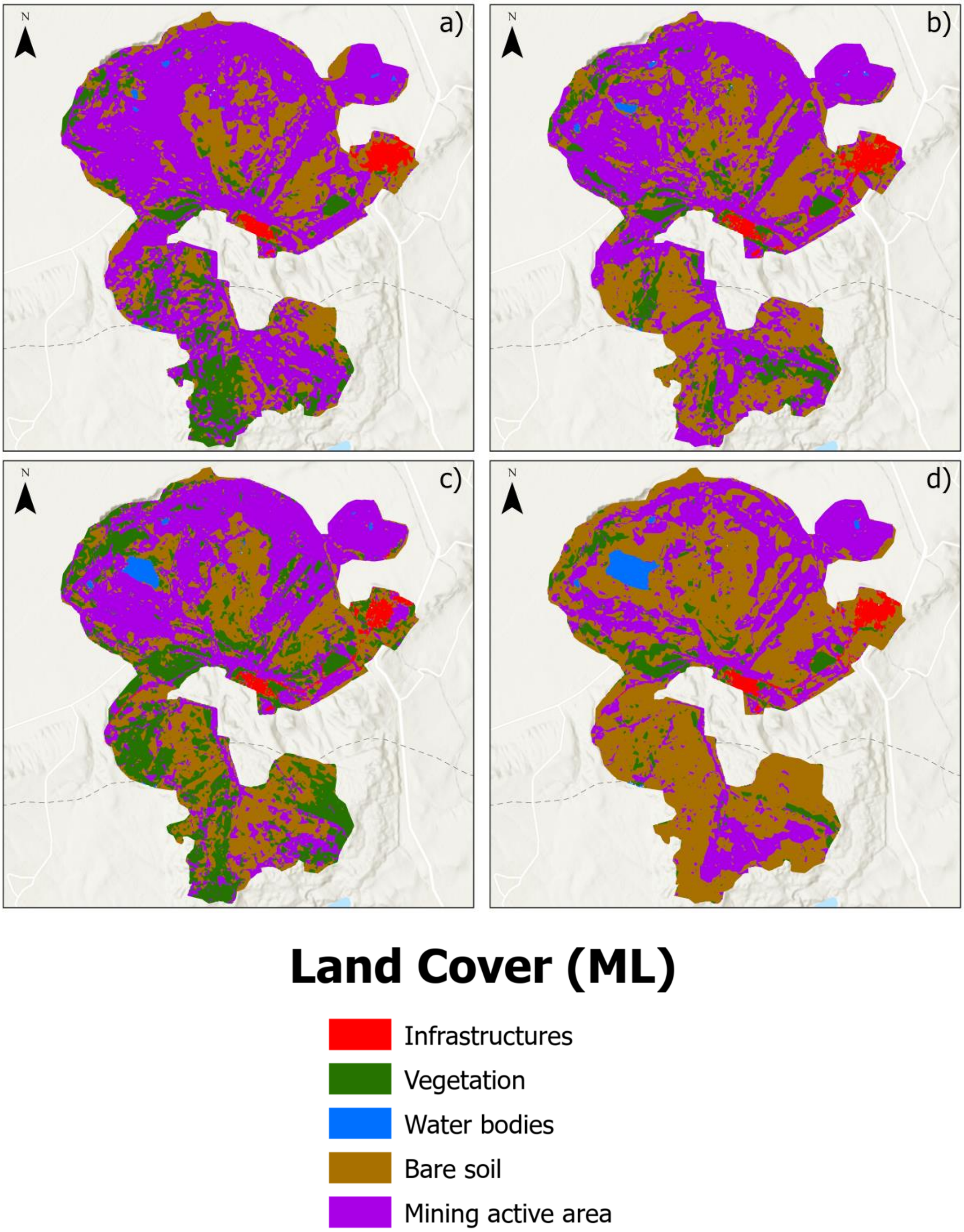

Figure 8 (a,b,c and d). ML spatiotemporal evolution from 2018 to 2021 a (upper left) to d (bottom right)

Table 5. Statistical analysis of the LC percentage coverage in Amynteo open-pit mine during the 2018 to 2021

Class/Year	2018	2019	2020	2021	Relative (%) change
Bare soil	27.35	36.60	31.72	57.74	111.14
Infrastructures	2.05	2.47	1.81	2.15	4.57
Mining active area	57.65	50.02	40.79	31.69	-45.01
Vegetation	12.73	10.55	24.71	6.76	-46.90
Water bodies	0.22	0.35	0.97	1.64	629.87

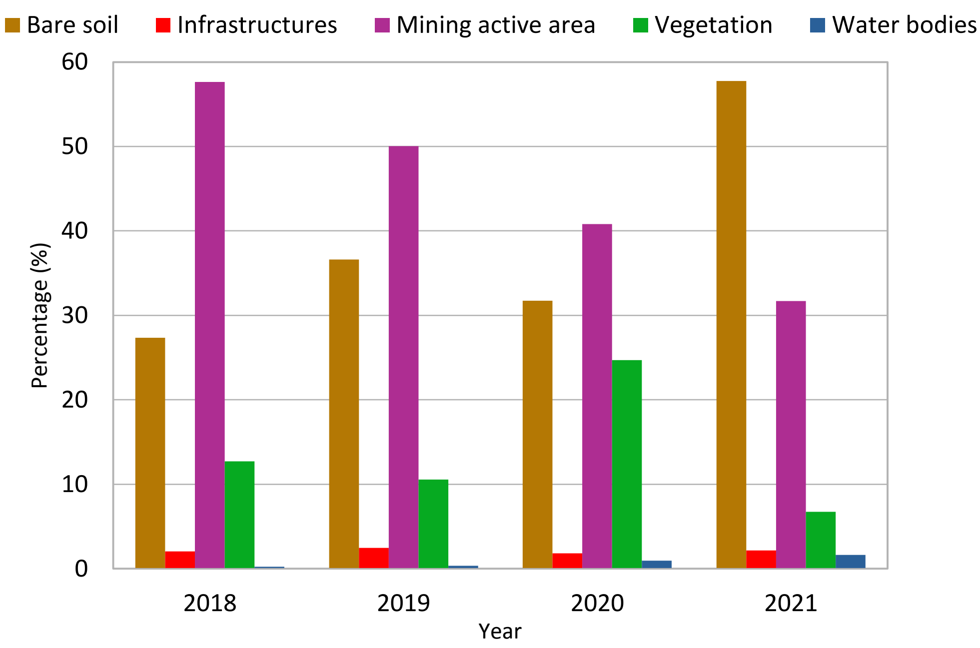

Figure 9. Histogram that represents the percentages of ML extents related to the spatiotemporal evolution from 2018 to 2021

Ptolemaida

Regarding the quantification of the results (Table 6) in the Ptolemaida open-pit, a different pattern was observed in the land cover chnages (Figure 10). Specifically, in terms of relative percentage, a small decrease of the mining active areas up to 7,96% was identified, while the bare soil and vegetation classes remained relatively stable with small increases up to 4.58% and 3.52% respectively. Based on the comparison between the "green transition" classes (bare soil, vegetation, water bodies) and the mining active areas, a slight trend towards the reclamation phase is evident (Figure 11). However, these rates are much lower compared to the Amynteo mine. It should be noted that a significant part of the Ptolemaida mine was active (2021), which justifies the difference between the two Greek study areas. Lastly, changes in water bodies are minor representing that water bodies in comparsion with the total coverage are minimum, during the period 2018 to 2021, which can be attributed to the activity of the mine (Figure 11).

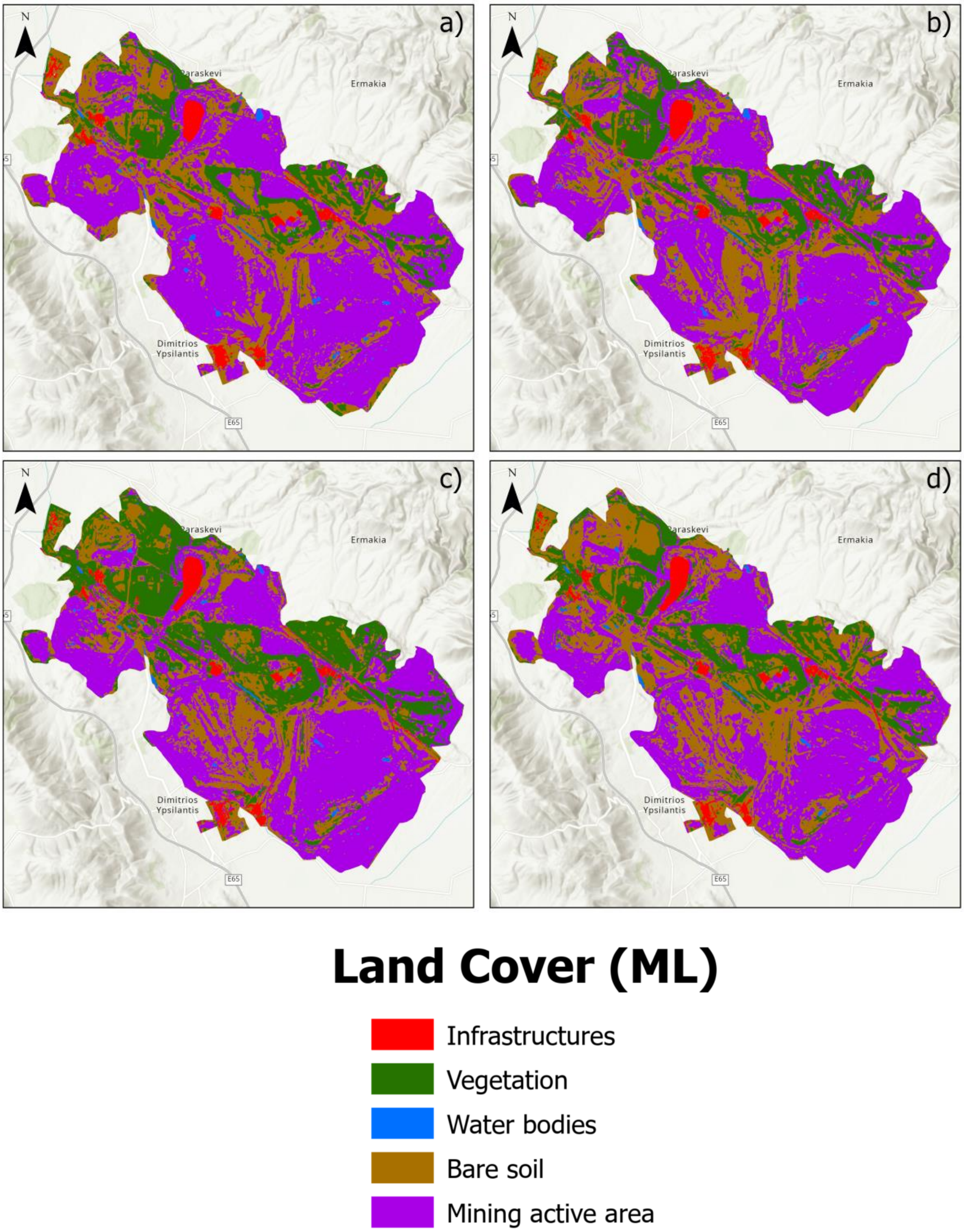

Figure 10. Figure. 10 (a,b,c and d). ML spatiotemporal evolution from 2018 to 2021 a (upper left) to d (bottom right)

Table 6. Statistical analysis of the LC changes in Ptolemaida open-pit mine during the 2018 to 2021

Class/Year	2018	2019	2020	2021	Relative (%) change
Bare soil	29.06	28.83	24.18	33.63	15.75
Infrastructures	2.90	2.93	3.13	2.79	-3.60
Mining active area	54.57	51.29	47.95	46.60	-14.59
Vegetation	12.86	16.29	24.18	16.38	27.36
Water bodies	0.61	0.65	0.55	0.57	-7.03

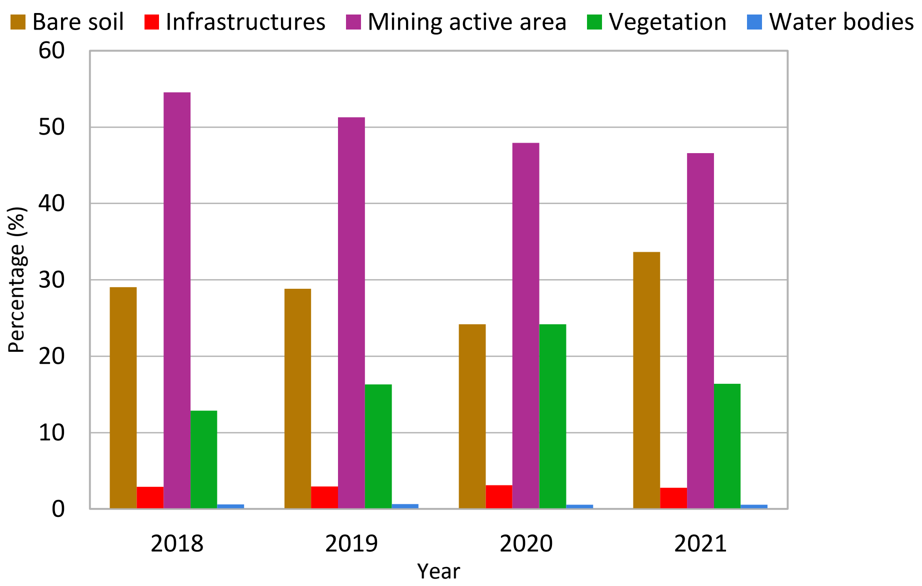

Figure 11. Histogram that represents the percentages of ML extents related to the spatiotemporal evolution from 2018 to 2021. The mining active area is illustrated in purple, bare soil in brown, the infrastructures in red, and water bodies in blue

KONIN REGION

Corine Land Cover spatiotemporal analysis

According to the quantification of the CLC products in Konin region (Table 7), an analysis of the spatiotemporal evolution was carried out during the time period 1990 to 2018 (Figure 12). Notably, there was a decrease of agricultural areas up to 6.35%, while the urban sub-categories (Industrial, commercial and transport units Mine, dump and construction sites, Urban fabric) and forest and seminatural areas increased by 73.26 % and 14.95%, respectively. Specifically, regarding the three urban sub-categories, the highest increase identified in urban fabric class accounted for up to 96.69%. This was followed by industrial, commercial, and transport units, which increased by 87%, and mine, dump, and construction sites, with a more moderate increase of 28.5%. Additionally, the wetlands decreased by 29.65%, while the water bodies increased up to 33.27%, during the observed period.

Table 7. Statistical analysis of the LU/LC changes in Konin region during the 1990 to 2018

	1990	2000	2006	2012	2018	Relative (%) change
Industrial, commercial and transport units	0.37	0.39	0.62	0.66	0.70	87
Mine, dump and construction sites	1.09	1.41	1.24	1.50	1.40	28.54
Urban fabric	1.86	2.18	3.34	3.63	3.65	96.69
Agricultural areas	78.64	77.18	74.20	73.62	73.64	-6.35
Forest and seminatural areas	15.96	16.75	18.50	18.45	18.34	14.95
Wetlands	0.82	0.74	0.63	0.58	0.58	-29.65
Water bodies	1.27	1.35	1.49	1.56	1.69	33.27

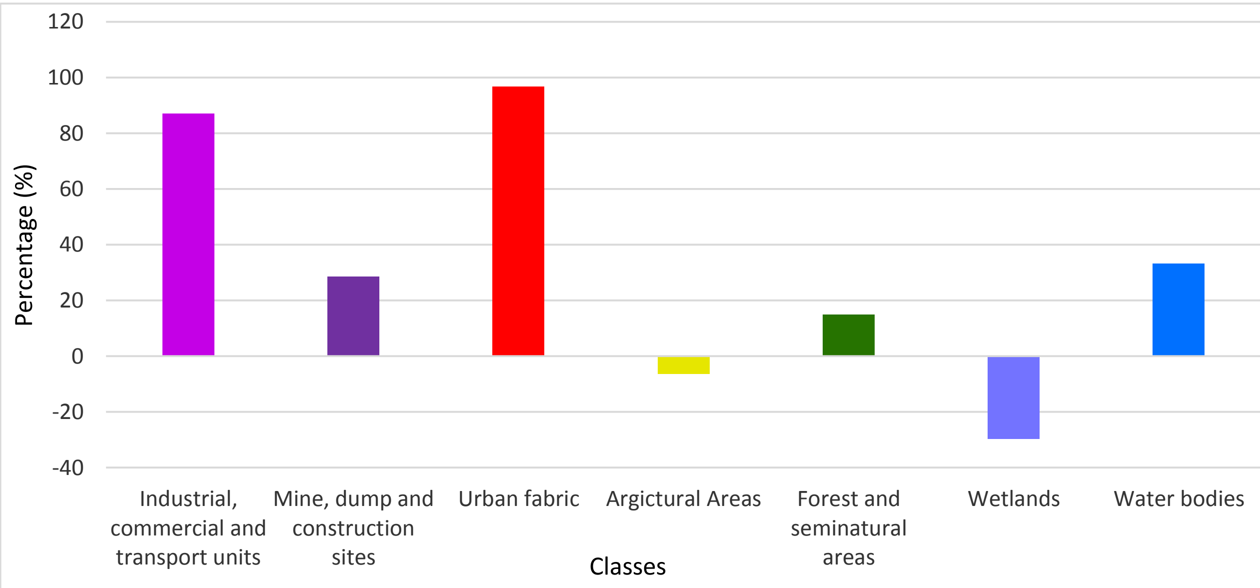

Figure 12. Figure 12. Relative percentage coverage increase or decrease of LC/LU types in Konin region, during the time during the 1990 to 2018. The violet color presents the “Industrial, commercial and transport units”, the purple color depicts “Mine, dump and construction sites”, the red color represents the “Urban fabric”, the yellow color depicts the “Agricultural areas”, the green color illustrates the “Forest and seminatural areas”, the blue color presents the “Wetlands” and dark blue color represents the “Water bodies”

Regarding the monitoring of spatiotemporal changes (Figure 13), the expansion of urbanization was observed in settlements near the Kazimierz, Jozwin, and Adamow mines. It's noteworthy that reclamation processes depicted in mining pits that existed in 1990, which have transformed into agricultural and semi-natural areas (Figure 14). Additionally, the evolution of the Jozwin open-pit mine is represented during the period from 1990 to 2018 (Figure 14). This involved changes in land uses, transitioning from arable lands to mine, dump, and extraction sites. These land use changes were accompanied by the expansion of existing settlements and the development of new ones near the industrial areas of the mining pit.

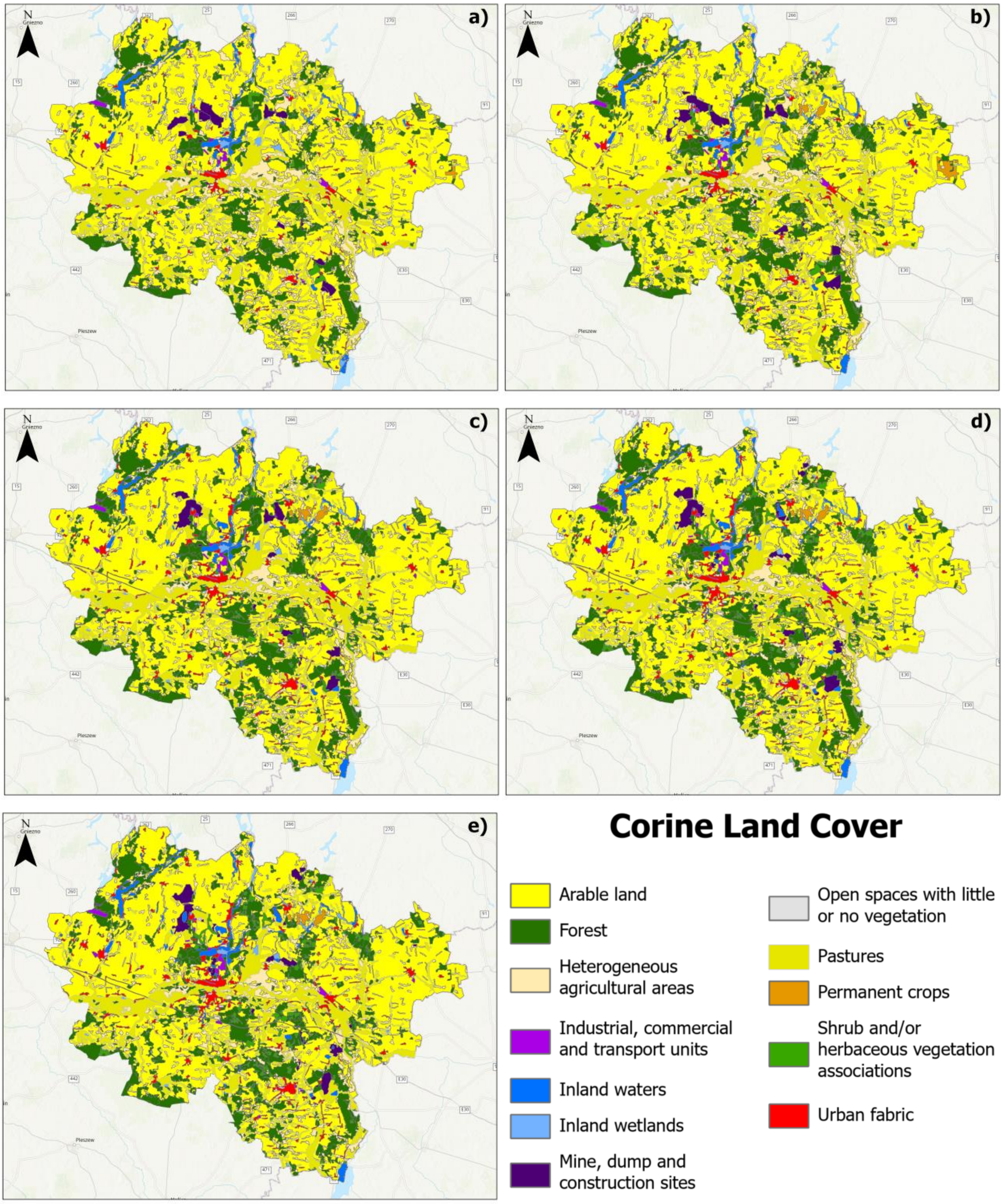

Figure 13. Figure 13. Corine Land Cover maps of Konin region during the time period a)1990, b) 2000, c) 2006, d) 2012, e) 2018. The yellow color represents “arable land”, dark green color depicts “Forest”, beige color illustrates “heterogeneous agricultural areas”, purple color presents “industrial, commercial and transport units”, dark blue color illustrates “inland water”, light blue color depicts “inland wetlands”, dark purple color presents “mine, dump and construction sites”, grey color represents “open spaces with little or no vegetation”, fade yellow(?) color depicts “pastures”, orange color presents “permanent crops”, green color depicts “shrub and/or herbaceous vegetation associations” and red color illustrates “urban fabric”.

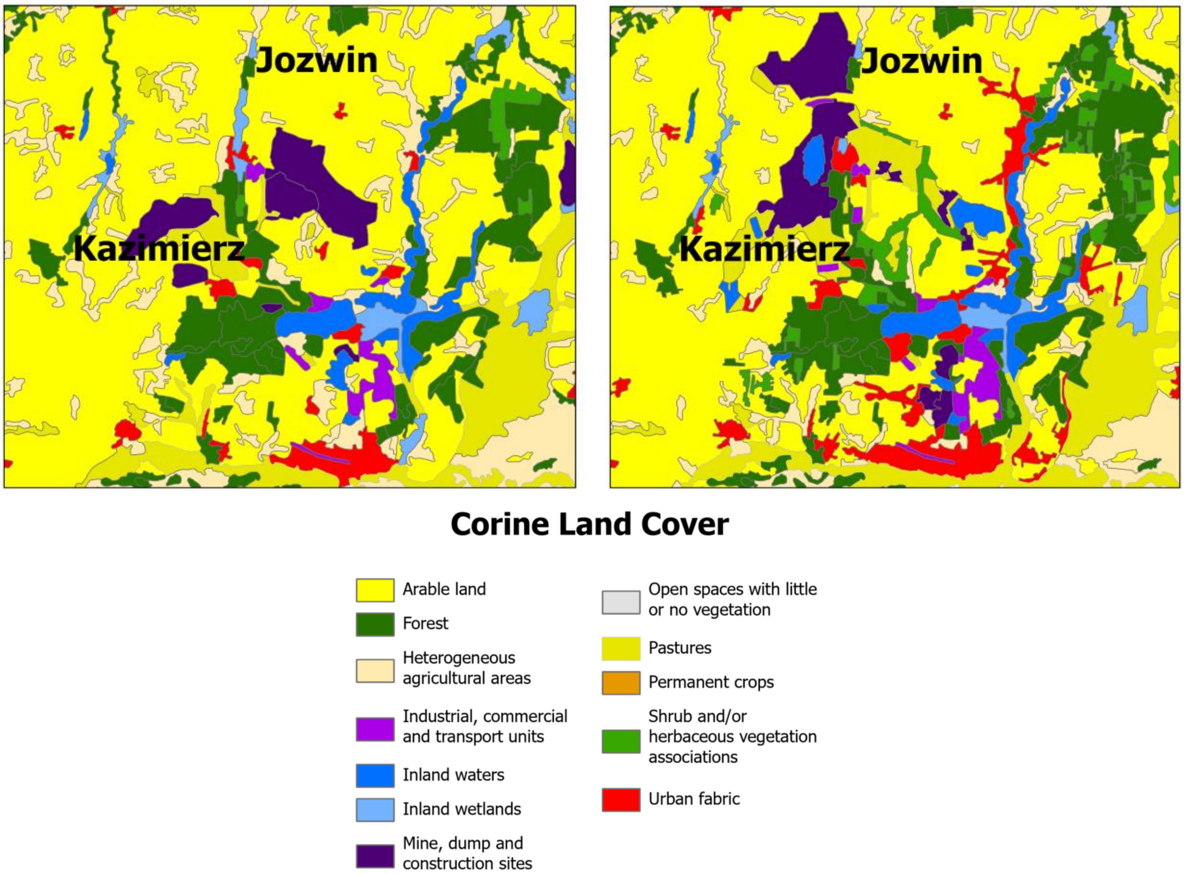

Figure 14. Comparison of LU/LC changes between the 1990 (left) and 2018 (right) in the wider area close to Kazimierz and Jozwin open-pit mines

Jóźwin

Based on the quantification of spatiotemporal results in the Jóźwin mine (Table 8), it is notable, the ongoing mining activity in the most area of the open-pit from 2018 to 2021 (Figure 15). The following diagram (Figure 16) depicts the land cover classes, indicating a relatively stable status for the mining activity. Particularly, in terms of relative percentage (Table 8), the mining activity areas decreased up to 12 %, while the vegetation class increased up to 402 %. Furthermore, the bare soil class maintains relatively stable with a small decrease up to 12 %, whereas water bodies indicating an increase up to 91.31%, during the 2018 to 2021. The ML products also depict reclamation process activities, especially in the southwestern site and an expansion of mining activities in the southeastern part of the mine (Figure 15).

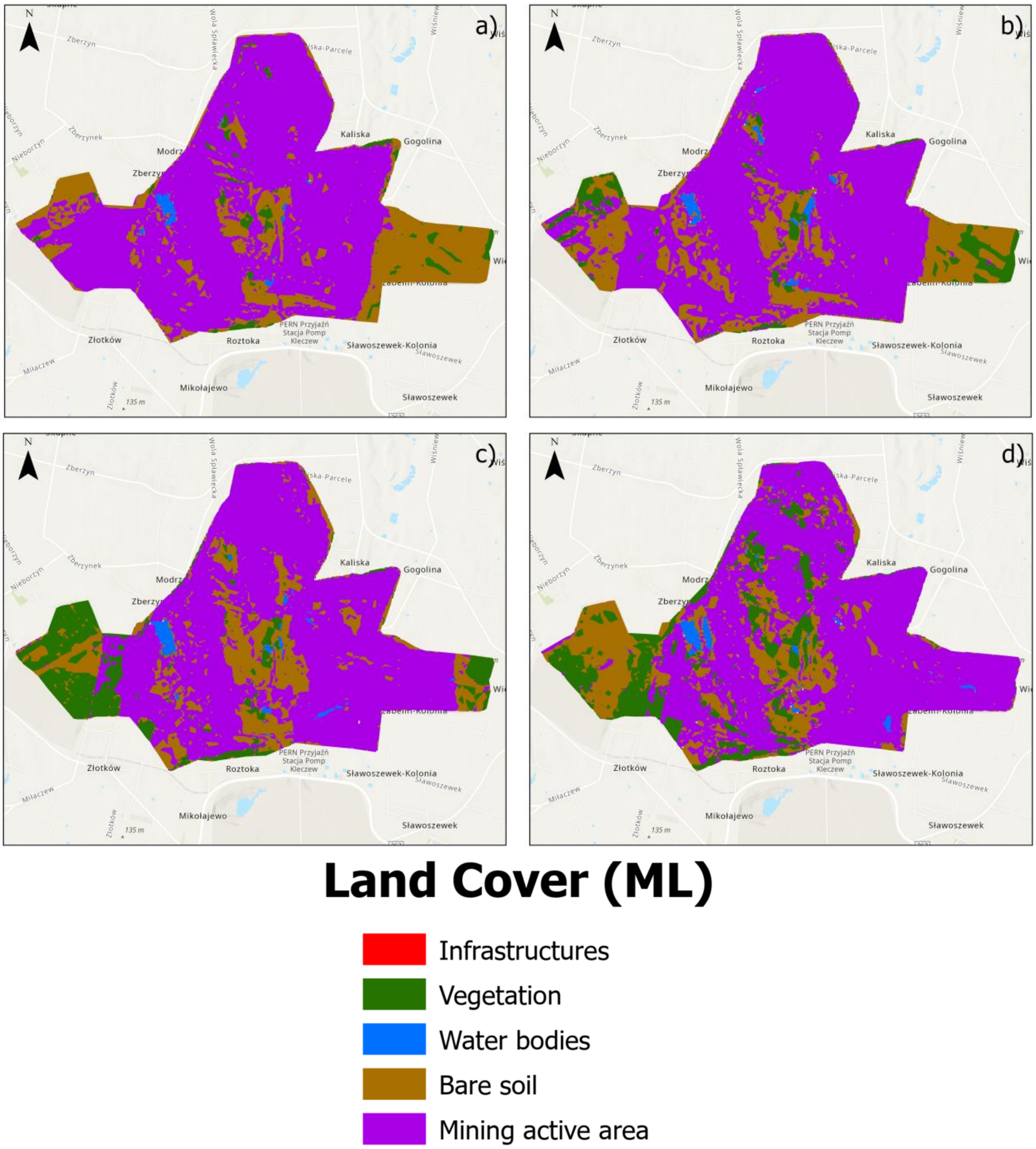

Figure 15 (a,b,c and d). ML spatiotemporal evolution from 2018 to 2021 a (upper left) to d (bottom right).

Table 8. Statistical analysis of the LC changes in Jozwin open-pit mine during the 2018 to 2021.

Class/Year	2018	2019	2020	2021	Relative (%) increase/decrease
Bare soil	23.41	22.39	18.94	20.57	-12.13
Infrastructures	0.00	0.00	0.00	0.00	0.00
Mining active area	73.16	70.82	67.80	64.37	-12.01
Vegetation	2.74	5.67	12.02	13.77	402.03
Water bodies	0.68	1.08	1.22	1.29	91.31

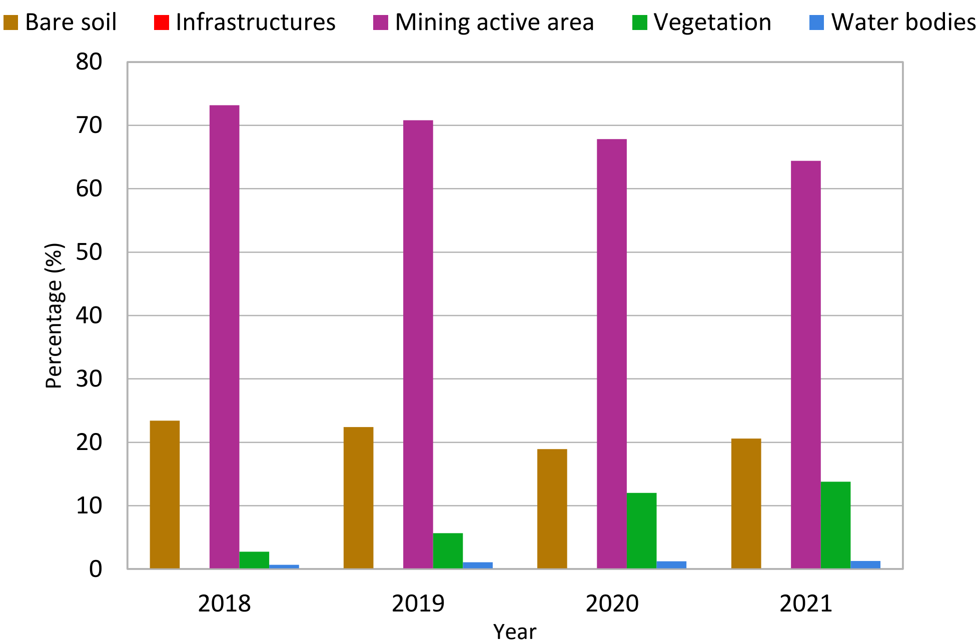

Figure 16. Histogram that represents the percentages of ML extents related to the spatiotemporal evolution from 2018 to 2021. The minining active area is illustrated in purple, bare soil in brown, the infrastructures in red, and water bodies in blue.

Kazimierz

Following the case of the Kazimierz mine, where industrial activities have already reduced, according to the fowling figures it is obvious that reclamation efforts are taken place especially in 2020 and 2021 (Figure 17 c,d). Specifically, based on the spatiotemporal evolution of LC, a significant portion of the mine boundaries has transformed from bare soil to vegetation (Figure 18), reaching a relative increase up to 466.94 % (Table 9).

Furthermore, the mining activity area exhibits a very small percentage of the total coverage in 2018, up to 12.65 %, compared to the other mines, indicating a substantial transformation towards a "green" state. Lastly, the coverage of water bodies is in high percentage values from the beginning of the processing period, with an increase up to 41.26% in 2021.

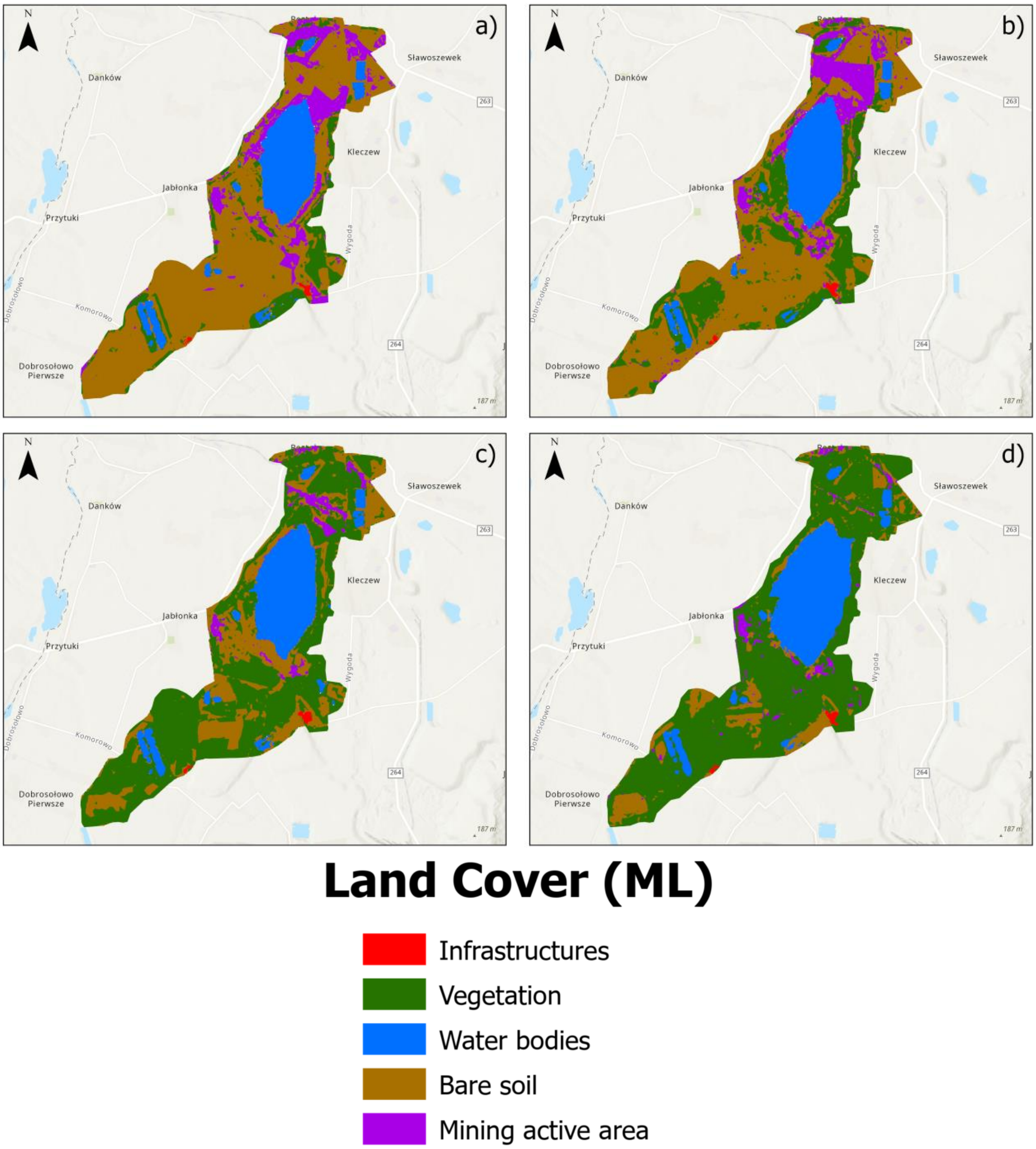

Figure 17 (a,b,c and d). ML spatiotemporal evolution from 2018 to 2021 a (upper left) to d (bottom right).

Table 9. Table 9. Statistical analysis of the LC changes in Kazimierz open-pit mine during the 2018 to 2021.

Class/Year	2018	2019	2020	2021	Relative (%) change
Bare soil	60.36	48.00	25.80	11.89	-80.30
Infrastructures	0.27	0.39	0.34	0.37	35.01
Mining active area	12.65	11.55	3.32	2.55	-79.81
Vegetation	11.15	23.87	52.62	63.22	466.94
Water bodies	15.55	16.17	17.91	21.97	41.26

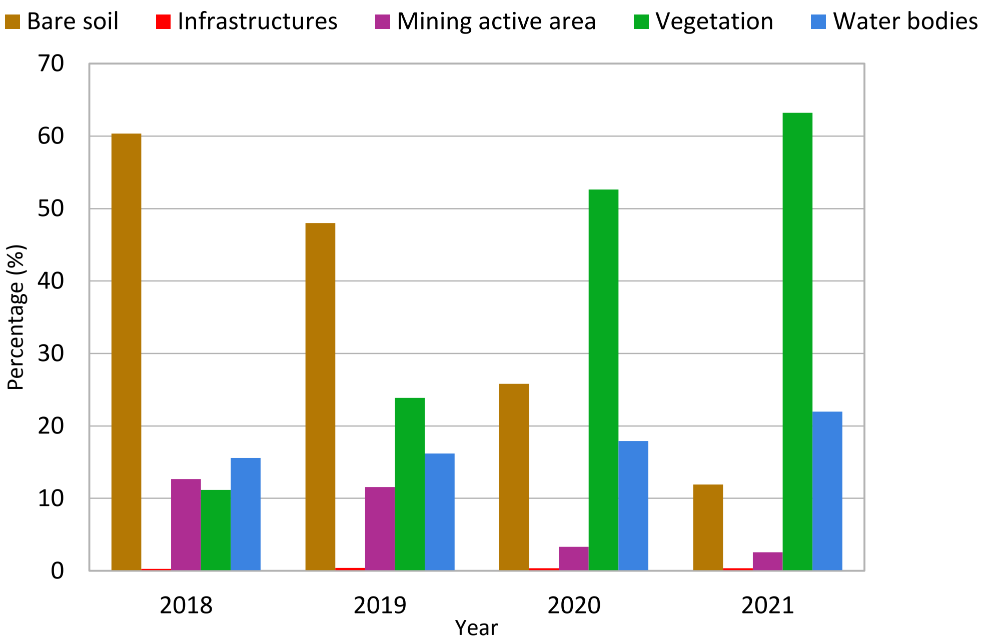

Figure 18. Histogram that represents the percentages of ML extents related to the spatiotemporal evolution from 2018 to 2021. The minining active area is illustrated in purple, bare soil in brown, the infrastructures in red, and water bodies in blue

Adamów

Regarding the spatiotemporal results at the Adamów mine, it is noteworthy that the reclamation phase is an ongoing process, particularly in the southern and western parts of the studied area (see Figure 19). Based on the changes in land cover (LC) over time, the coverage of mining activity areas has decreased by 19.90% in relative terms (as shown in Table 10), while the Bare Soil and Vegetation classes have increased by 10.09% and 67.83%, respectively. In terms of 'green transition' classes illustrate a positive trend, representing up to 60% of the total coverage of the Adamów mine. On the other hand, the coverage of water bodies remained relatively stable, with a slight increase of 7.18% during the period from 2018 to 2021 (Figure 20).

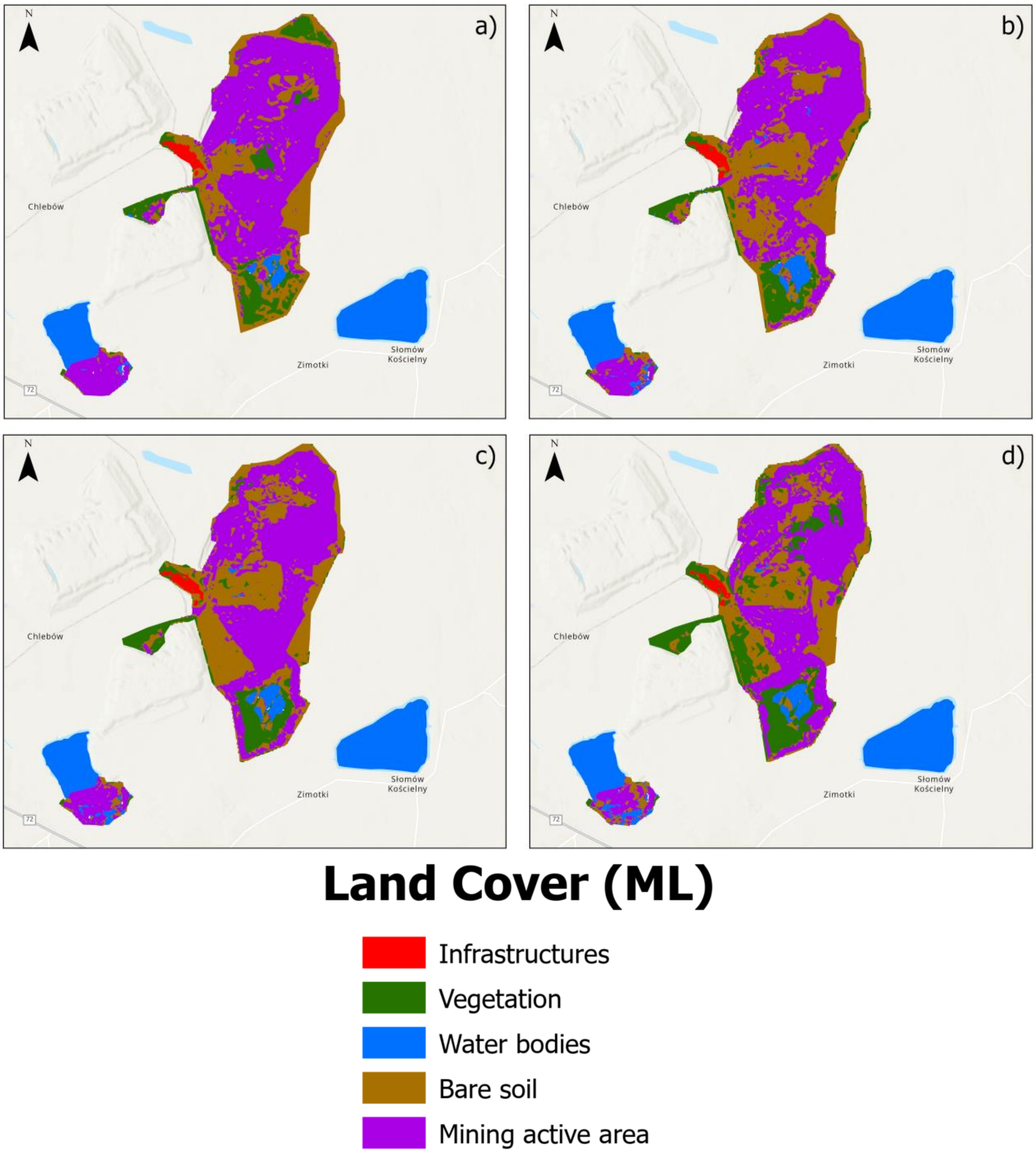

Figure 19 (a,b,c and d). ML spatiotemporal evolution from 2018 to 2021 a (upper left) to d (bottom right).

Table 10. Table 10. Statistical analysis of the LC change in Adamow open-pit mine during the 2018 to 2021.

Class/Year	2018	2019	2020	2021	Relative (%) change
Bare soil	23.47	30.14	29.31	25.84	10.09
Infrastructures	1.14	1.18	1.01	0.86	-24.14
Mining active area	48.36	42.56	43.33	38.74	-19.90
Vegetation	9.25	7.22	7.75	15.53	67.83
Water bodies	17.76	18.89	18.60	19.04	7.18

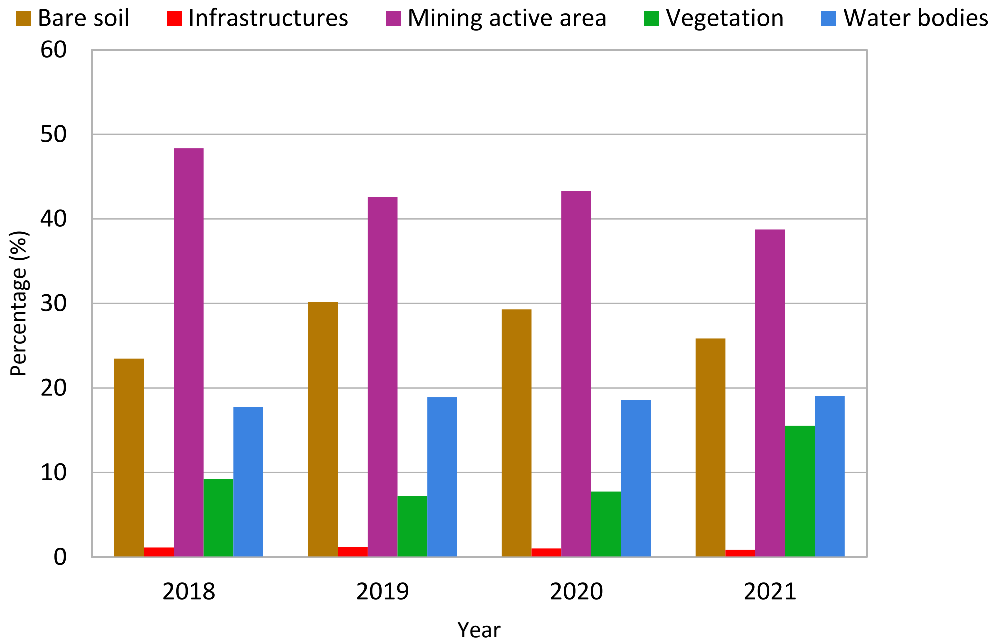

Figure 20. Figure 20. Histogram that represents the percentages of ML extents related to the spatiotemporal evolution from 2018 to 2021. The minining active area is illustrated in purple, bare soil in brown, the infrastructures in red, and water bodies in blue

RUHR AREA

Corine Land Cover spatiotemporal analysis

In the Ruhr area, quantification of the CLC products revealed that the reclamation processes have already started from 1990 (Figure 21). In particular, there was an increase in manmade environments as well as in forested and semi-natural areas, in terms of relative changes (Table 11), by up to 16.77. Specifically, the most significant increases were identified in the urban fabric and in industrial, commercial, and transport units, reaching up to 9.25% and 34%.

On the other hand, the areas designated as mines, dumps, and construction sites decreased by 51.46 %, highlighting the reclamation efforts in the Ruhr area. Additionally, water bodies increased by 38.41%, while wetlands decreased by up to 75.5%.

Table 11. Statistical analysis of the LU/LC change in Ruhr area during the 1990 to 2018

Class/Year	1990	2000	2006	2012	2018	Relative (%) change
Industrial, commercial and transport units	5.81	6.19	6.27	7.71	7.81	34.36
Mine, dump and construction sites	1.17	1.13	1.11	0.62	0.57	-51.46
Urban fabric	24.43	24.88	25.23	26.68	26.70	9.26
Agricultural Areas	51.28	50.34	49.92	44.56	44.48	-13.26
Forest and seminatural areas	15.96	15.90	15.86	18.68	18.64	16.77
Wetlands	0.05	0.05	0.05	0.00	0.01	-75.59
Water bodies	1.30	1.51	1.56	1.76	1.80	38.41

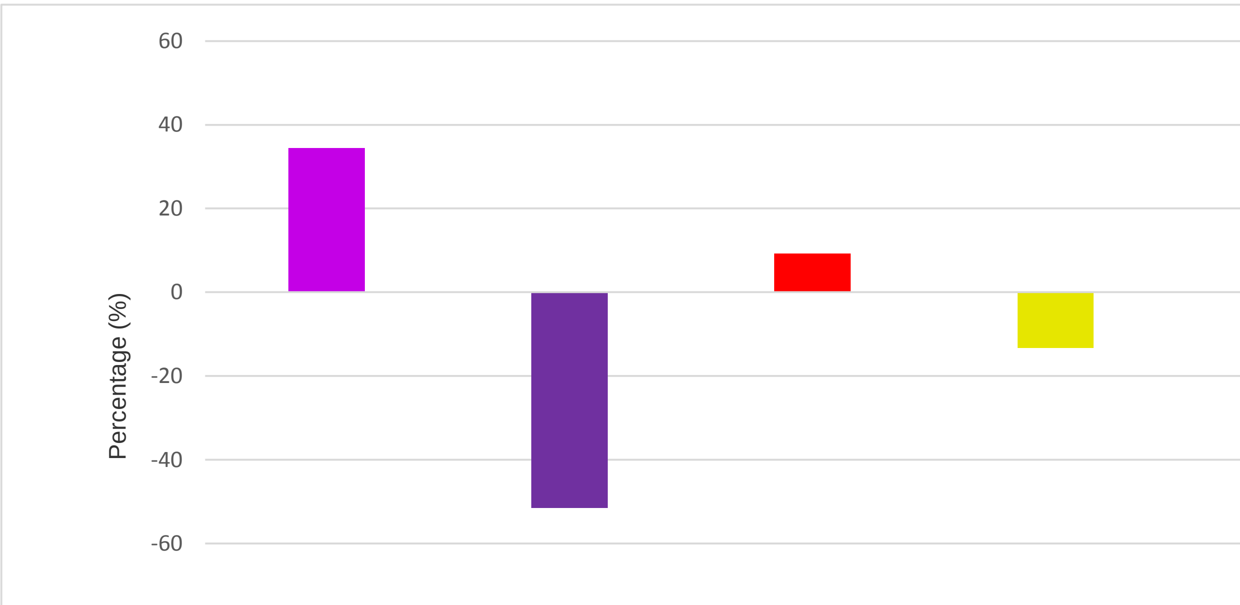

Figure 21. Relative percentage coverage increase or decrease of LC/LU types in Rurh area, during the time during the 1990 to 2018. The violet color presents the “Industrial, commercial and transport units”, the purple color depicts “Mine, dump and construction sites”, the red color represents the “Urban fabric”, the yellow color depicts the “Agricultural areas”, the green color illustrates the “Forest and seminatural areas”, the blue color presents the “Wetlands” and dark blue color represents the “Water bodies”.

From the perspective of spatiotemporal LU/LC changes (Figure 22), a substantial portion of the mine, dump and construction sites converted to industrial and commercial units as well as to water bodies, forest and seminatural areas. These changes illustrating the advanced reclamation and rehabilitation processes of Ruhr area that have been implemented since the 2018 (Figure 23).

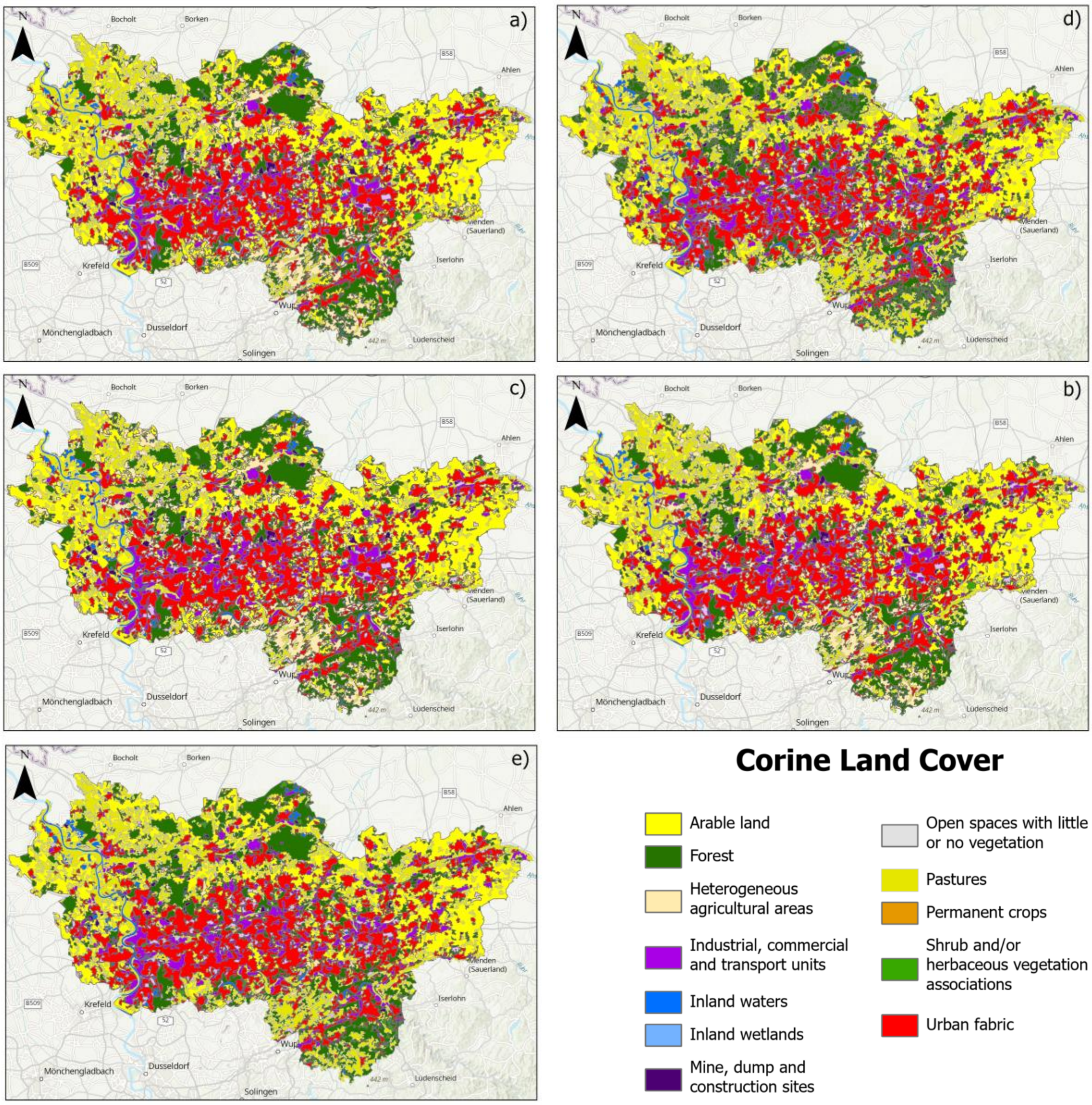

Figure 22. Corine Land Cover maps of Ruhr area during the time period a)1990, b) 2000, c) 2006, d) 2012, e) 2018. The yellow color represents “arable land”, dark green color depicts “Forest”, beige color illustrates “heterogeneous agricultural areas”, purple color presents “industrial, commercial and transport units”, dark blue color illustrates “inland water”, light blue color depicts “inland wetlands”, dark purple color presents “mine, dump and construction sites”, grey color represents “open spaces with little or no vegetation”, fade yellow(?) color depicts “pastures”, orange color presents “permanent crops”, green color depicts “shrub and/or herbaceous vegetation associations” and red color illustrates “urban fabric”.

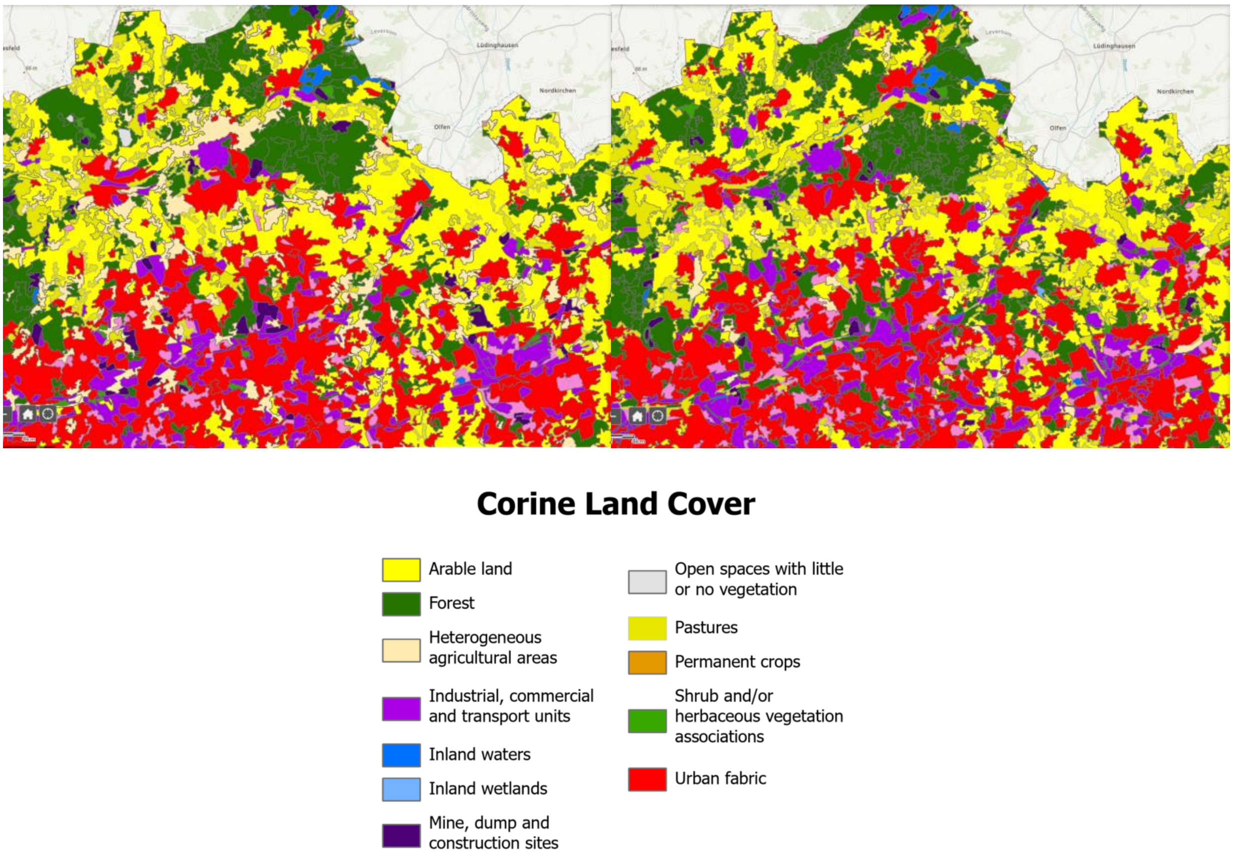

Figure 23. Comparison of LU/LC changes between the 1990 (left) and 2018 (right) in the southern side of the Ruhr area, southwest of Dortmund city

1.4. SUMMARY

The objective of this section was the assessment of the spatiotemporal evolution the three regions (Western Macedonia, Konin, Ruhr) as well as the open-pit mines in Western Macedonia and Konin region. Specifically, the regional spatiotemporal evaluation was implemented by analyzing and quantifying the CLC products during the time period of 1990 to 2018, while the asset analysis of open-pit mines was carried out using a machine learning approach. Particularly, five land cover classes were selected and defined: a) Bare soil, b) Infrastructures, c) Mining active area, d) Water bodies, and e) Vegetation. The coverage of each class was quantified to enable comparison and evaluation across both study areas. The results of this subtask, particularly the land cover results from 2021, could serve as the foundation for the spatial analysis in Subtask 2.3.2, which aims to identify renewable energy source (RES) utilization options.

Regarding the Greek case study, the Western Macedonia region is oriented towards to an industrial development with an increase of mine, dump and construction sites and the expansion of urban environment during the time period of 1990 to 2018. From the perspective of ML approach, the classification and quantification of the results revealed that the Amynteo mine open-pit has made significant progress in terms of green transition, during the time period 2018 to 2021. A part of the mining active areas has been transformed into bare soil and vegetation, indicating its potential for future reclamation purposes. Additionally, the evolution of a large artificial pit-lake in the western area of the mine indicate reclamation efforts. In contrast, the Ptolemaida mine exhibits lower transition rates with relative small changes in land cover classes. It should be noted that a significant portion of the Ptolemaida mine is still operational, while the Amynteo mine has been closed since August 2020.

In the Polish study area, the Konin region has a strong orientation towards to industrialization, mining and urban growth, possibly at the expense of agricultural and natural wetland areas during the time period of 1990 to 2018. Regarding the ML approach, the Kazimierz mine has shown the biggest changes in terms of green transition during the observation period of 2018 to 2021. Particularly, Kazimierz was in an advanced phase of closure compared to the other two mining pits in Poland. Specifically, the bare soil class, which had the highest land cover percentage in 2018, has transitioned into vegetation, while the mining active areas has a minimum change about less than 3% of the total mine coverage. The Adamów mine follows as second in terms of green transition term showing an increasing trend until 2021. Lastly, the Jozwin mine exhibits the lowest transition trend due to its status as an active industrial area. However, satellite observations indicate that the western part within the mine boundaries has experienced a transition from processing sites to bare soil and vegetation, creating a suitable ground for future reclamation activities.

Lastly, the Ruhr area was analyzed only in regional scale due to its advanced transition and reclamation phase in former open-pit sites. The spatiotemporal analysis during the time period 1990 to 2018 indicates these processes with the significant decrease of mines, dumps and construction sites and the increase of water bodies, the industrial sites and the forested areas. Specifically, there are areas that were completely converted to agricultural and vegetated areas. Based on the geospatial and statistical results, the land cover changes consist of the reclamation and rehabilitation processes with the development of artificial lakes in mine open-pits, the construction of modern industrial and recreational zones, as long as forest and physical environments.

2. SPATIOTEMPORAL EVALUATION OF SATELLITE AND AERIAL PHOTOS TO IDENTIFY REUTILIZATION OPTIONS (GEOTHERMAL, WIND, SOLAR)

Renewable Energy Sources (RES) seems to be a prominent use for the rehabilitated lands of the former lignite mines of Greece and Poland. Especially for the Greek area, 19 applications for power production licenses were submitted to the Regulatory Authority for Energy (RAE) by Public Power Corporation Renewables (PPC Renewables) between 2018 and 2019, along with photovoltaic panel installation studies. This task describes the methodology for the preliminary suitability analyses of selected (RES) and particularly wind and solar parks. The assessment that was implemented for the Greek region is located nearby Ptolemaida mine and for Poland within the boundaries of Kazimierz, Jóźwin, and Adamów mines. The high infrastructure costs combined with other complexities excluded geothermal potential from this subtask. The different environments in the regions near the Ptolemaida mine in Greece and the Kazimierz, Jóźwin, and Adamów mines in Poland, consist of a variety of geographical, morphological, and socio-economic factors. In terms of geography, the topography, climate, and natural landscapes surrounding the Ptolemaida mine in Greece can be vastly different from those around and within the boundaries of Polish mines. Understanding these factors for each location would allow for a more comprehensive justification of the differences between the different environments of the mining regions in Greece and Poland.

2.1. DATA SPECIFICATION

According to the applied methodology FABDEM (Forest And Buildings removed Copernicus DEM) which is a Digital Elevation Model (DEM) based on the Copernicus GLO 30 DEM at 1 arc second (~30 m) grid spacing was implemented successfully. Specifically, this is product is produced with a novelty of removing building and tree height using a machine learning approach to produce a global elevation map with buildings and forests removed (Hawker et al., 2022). Under this light, it can be utilized for applications that requires a more reliable view of the surface as well as the flatness of the study area. Lastly, in order to assess the RES potential of the selected sites from the implemented scenario of RES, the wind and solar potential of the study areas was taken into consideration, i.e., mean wind speed (at a height of 100 m) and various types of solar irradiation, respectively. Specifically, wind potential was obtained from the Global Wind Atlas v 3.3 (https://globalwindatlas.info, accessed on 30 July 2023), a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). Solar radiation was retrieved from the “Global Solar Atlas v 2.8 (https://globalsolaratlas.info, accessed on 30 July 2023, a free, web-based application is developed and operated by the company Solargis s.r.o. Other datasets such Natura 2000, river and road network were collected from open-source portals such Open Street Map and European Environmental Agency.

2.2. METHODOLOGY

In particular, proximity criteria were implemented from the following legislations (Tables 12 & 13) in order to be integrated in a GIS approach using open source-data related to geomorphology, the wind energy potential, the Land Cover (LC) and the infrastructures of the study areas. Specifically, the ML products were utilized from the previous subtask 2.3.1 and were used as land cover/land use categories for the Polish region. Additionally, in the case of Greek region, CLC 2018 products were used to for the implementation of LC criterion due to the fact that ML products were generated only within the boundaries of the open-pit mines. In general, the proximity limits took into consideration; i) the distance to infrastructure such as road and rail networks, ii) the distance from settlements, iii) the distance to the major drainage network, iv) the proximity to NATURA and v) the proximity to cultural heritage sites. According to the Wind potential, open-source datasets were obtained and processed from Wind ALTAS in order to be used as threshold value in areas where the wind speed was too low to meet the sustainable requirements of the Wind Park installation. Regarding the existing literature, the minimum wind speed for the preliminary construction of WP was greater than 5 m/s.

Furthermore, additional open-source dataset was utilized such as Solar ATLAS in order to highlight the areas with the highest Direct Normal Irradiation (DNI), which can be used for preliminary analysis from stakeholders for the most productive areas on the areas under examination in terms of solar energy. Particularly, the DNI is referred to a surface perpendicular to the Sun, while the term solar irradiance represents the power from the sun that reaches a surface per unit area.

Table 12 Proximity limitations according to legislations of each country for the installation of Wind Parks

Factors	Proximity / value	
	Greece	Poland
Transportation network	Transportation grid is in direct proximity, since all suitable areas are close to existing network.	6 – 50 m
Railways	100 m	20 m
Airports	3000 m	Limitation surfaces are defined based on factors such as airport runways and approach category etc.
Settlements > 2000 residents	1000 m	700 m
Traditional settlements	1500 m	700 m
Other settlements	500 m	700 m
Electrical grid*	Electric grid is in direct proximity, since all suitable areas are close to existing network.	
NATURA 2000	1000 m	500 m (not less than ten times the height of the wind farm)
World Heritage List, other major monuments, archaeological sites & historical sites	3000 m	Limited extent and under the supervision of conservation services.
Rivers / Natural lakes	300 m	100 m

Table 13. Proximity limitations according to legislations of each country for the installation of Photovoltaic Parks

Factors	Proximity / value	
	Greece	Poland
Transportation network	Transportation grid is in direct proximity, since all suitable areas are close to existing network.	
Railways	100 m	20 m
Airports	3000 m	Limitation surfaces are defined based on factors such as airport runways and approach category etc.
Settlements	500 m	No fixed standards
Electrical grid*	Electric grid is in direct proximity, since all suitable areas are close to existing network.	
NATURA 2000	1000 m	No fixed standards
Rivers / Natural lakes	300 m	100 m
Slope	> 10% are unsuitable	-

Following the proximity criteria, topographical and morphological parameters were processed in order to exclude unsuitable areas for wind and photovoltaic parks installation. Particularly for the determination of preliminary suitable sites for PV installation slope criterion was analyzed based on open-source Digital Elevation Models and existing topography. According to the existing literature, areas with a slope percentage lower than 5 are considered as zones with acceptable flatness

Lastly, the generated ML products were utilized as on/off criteria (Table 14 & 15) to exclude areas that are characterized as unsuitable due to their Land Cover category. The land cover types that were considered as suitable for RES installation were the bare soil (ML class: Bare soil), the sparse vegetation (ML class: Bare soil), and the cultivated areas (ML class: Vegetation). Under this aspect, ML products were combined with visual observation of satellite images and high-resolution ESRI basemaps for the better identification of suitable areas.

Table 14. Restriction (On/Off) criteria for the installation of Wind Parks according the Land Cover classes within and nearby to the boundaries of mine open-pits based on the Machine Learning and CLC products

Land Cover Factors	Greek	Polish
Cultivation and bare surface areas and/or with sparse vegetation (ML class: Bare soil)	Suitable areas	
Forests &transitional woodland shrub / Sparsely vegetated areas (ML class: Vegetation)	Unsuitable areas	Possible if natural function of the forest is not limited. Is to be avoided if possible.
Mining facilities (ML class: Built-up areas)		Unsuitable areas
Mineral extraction sites (ML class: Processing/active regions)		
Pit-lakes (ML class: Water bodies)		

Table 15. Restriction (On/Off) criteria for the installation of Photovoltaic Parks according the Land Cover classes within the boundaries of mine open-pits based on the Machine Learning products

Land Cover Factors	Greek	Polish
Cultivation and bare surface areas and/or with sparse vegetation (ML class: Bare soil)	Suitable areas	
Forests &transitional woodland shrub / Sparsely vegetated areas (ML class: Vegetation)	Unsuitable areas	
Mining facilities (ML class: Built-up areas)		
Mineral extraction sites (ML class: Processing/active regions)		
Pit-lakes (ML class: Water bodies)		

2.3. RESULTS

ADJACENT REGION TO PTOLEMAIDA MINE

The Area Of Interest (AOI) for the implementation of the scenarios for the installation of Renewable Energy Sources (RES) is located close to the southwest side of the Ptolemaida mine (Figure 24). Particularly, the AOI is mostly a mountainous area (Figure 25) with an altitude that ranges from 667m to 2102 m, with an average elevation of 1125 m. Specifically, the higher altitudes are located in the western side of the AOI, while on the eastern side are more planar surfaces with lower elevation. According to the Corine Land Cover 2018 (Figure 25), the eastern part is characterized by arable lands and agricultural activities, the northwestern side is covered by forests and natural grassland, while the wider region is classified as sparsely vegetated areas.

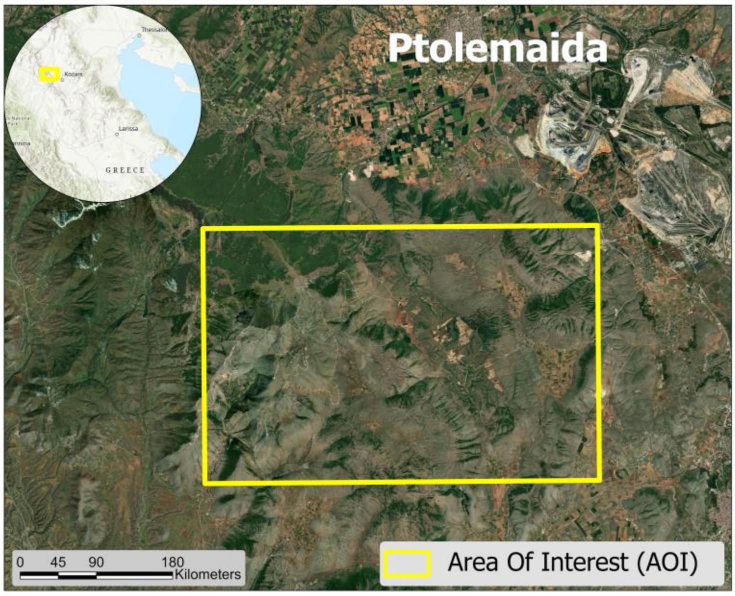

Figure 24. Greek case study boundary

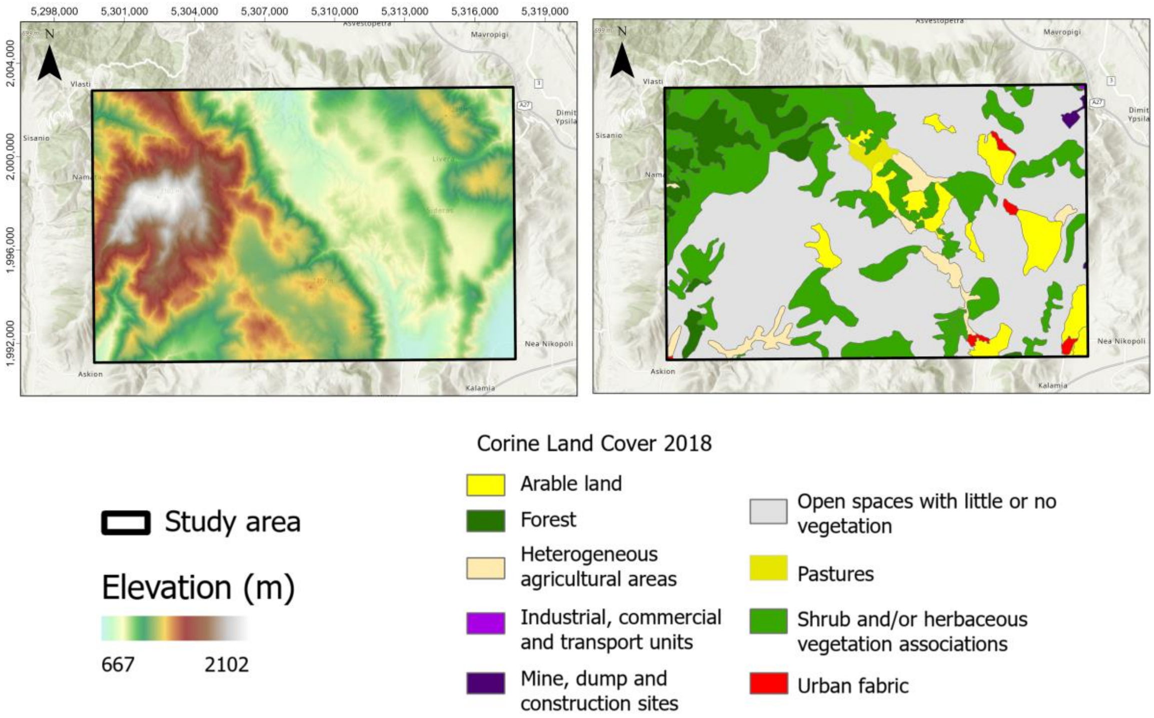

Figure 25. Map of Digital Elevation Model (left) and Corine Land Cover 2018 (right), of the Greek case study

GEOSPATIAL & SCENARIO ANALYSIS FOR RES

Geographic information systems (GIS) and associated spatial analysis that integrate GIS capabilities are frequently utilized in scenario planning (Abou Jaoude et al., 2022;Chakraborty and McMillan, 2017, Krassakis et al.). GIS technologies can support the scenario planning, at preliminary level integrating data from multiple sources. This becomes particularly valuable in the area of regional development and energy transition strategy, where the aspect to present sutainble solutions based on scenarios can support decision-making processes. As demonstrated by the areas under examination, the use of GIS and scenario planning have concluded to useful results in terms of RES suitability.

PV & WP SCENARIO FOR GREEK CASE STUDY

The following results (Figure 26) based on the above-mentioned criteria, highlighting with yellow color the more suitable areas for the installation of PV, where the surface is flatter with values less than 10 percent. Specifically, the largest extent of suitable areas is concentrated in planar sites in the eastern part of the AOI, as well as in the southern site where the elevation has lower values, with a total coverage up to 34.63 Km2 (Table 16).

Regarding the installation of WP, the suitable areas are illustrated with blue color in the western part of the AOI, where the altitude is higher than 889 m, with a total coverage up to 28.19 Km2.

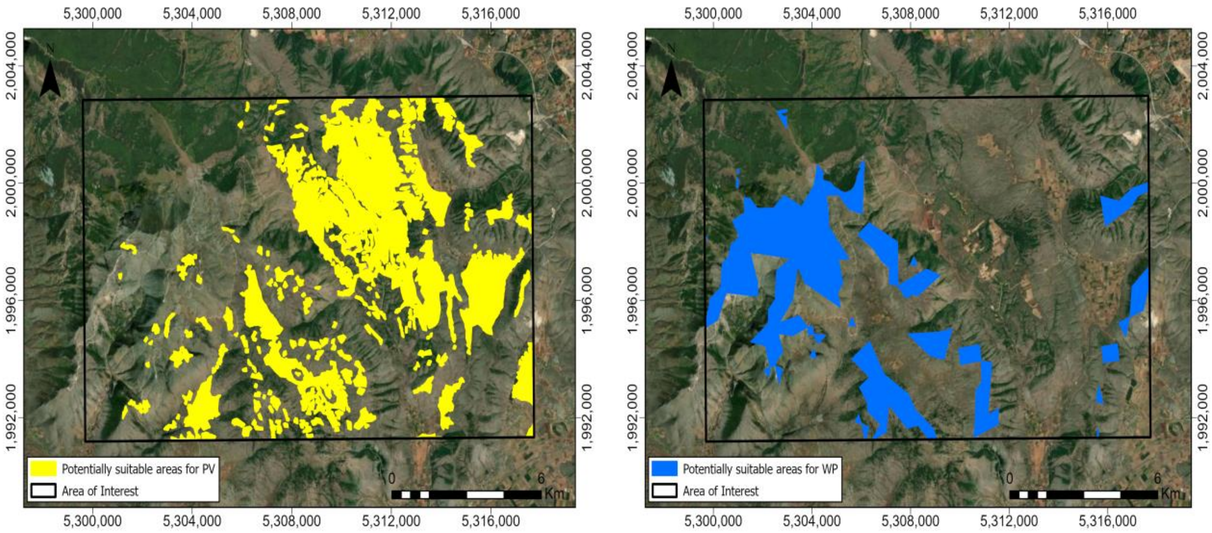

Figure 26. Preliminary suitability maps for the installation of Renewable Energy Sources (RES) in Western Macedonia close to the Ptolemaida open-pit mine. The left map illustrates with yellow color the suitable areas for Photovoltaic parks, the right map presents with blue color the suitable sites for Wind Parks.

Additionally, in Figure 27 areas with green color are considered as suitable for both types of RES in terms of overlapping. These areas are approximately up to 1.71 Km2 and are located in planar sites in the eastern and southern part of the AOI. In Table 15, the total coverage of renewable energy sources nearby the Ptolemais mines is depicted, where the 'Coverage percentage (%)' column represent the proportion of the mine's total extent that could potentially be utilized for each type of renewable energy source. Particularly the 13.41% can be used for 'Potentially suitable areas' for WP, which corresponds to 28.19 square kilometers of the mine's total area. Similarly, the 16.48% of the total area can be used for PV and 15.72%. On the other hand, only 4.94 % (figure 27) consist of the overlapped area that can be used for both RES, due to the mountainous topography of the study area nearby to Ptolemais mine.

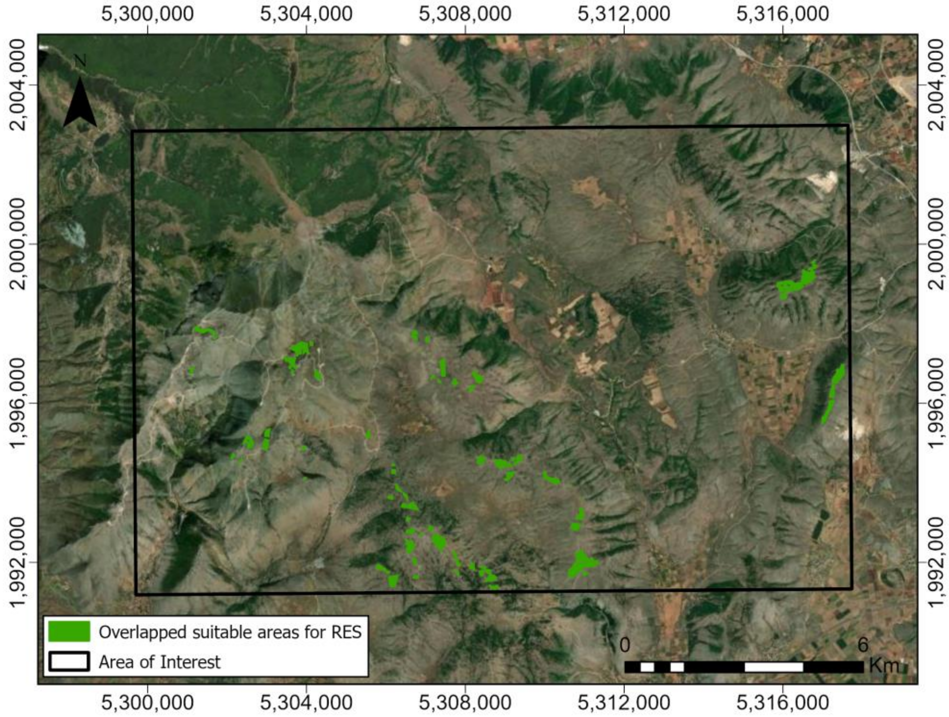

Figure 27. Preliminary suitability maps for the installation of Renewable Energy Sources (RES) in Western Macedonia close to the Ptolemaida open-pit mine. The map depicts with green color the overlapped areas for both types of RES

Table 16. Total coverage in percentage for the preliminary installation of the Renewable energy sources in Western Macedonia close to the Ptolemaida open-pit mine

Type of Renewable energy sources	Total coverage (Km^2)	Coverage percentage (%)
Potentially suitable areas for Wind Parks	28.19	13.41
Potentially suitable areas for Photovoltaic Parks	34.63	16.48
Overlapped areas for Renewable energy sources regarding the total extent of the mine.	1.71	4.94

PV & WP SCENARIO FOR POLISH CASE STUDY

JÓŹWIN

According to the Polish case study, the potential suitable areas for the installation of PV, which are mainly located in the western and the southern part of the Jóźwin (Figure 28) with the total coverage up 2.4 Km2. In case of WP, the suitable areas are illustrated with blue color covering similar areas as the PV with additional coverage in the central side of the mine covering up to 2.84 Km2.

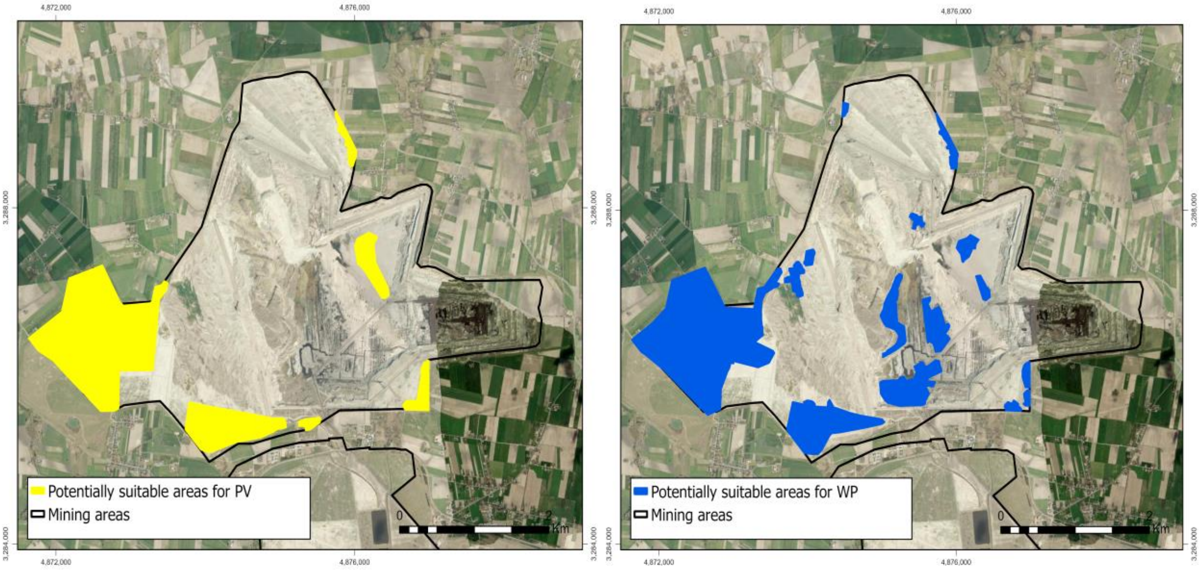

Figure 28. Suitability maps for the installation of Renewable Energy Sources (RES) in Jóźwin mine. The left map illustrates with yellow color the suitable areas for Photovoltaic parks, the right map presents with blue color the suitable sites for Wind Parks.

In Table 17, the total coverage of renewable energy sources within the boundaries of the Jóźwin mine is calculated, where the 'Coverage percentage (%)' column represent the proportion of the mine's total extent that could potentially be utilized for each type of renewable energy source. Particularly the 19.27% can be used for 'Potentially suitable areas' for WP, which corresponds to 2.84 square kilometers of the mine's total area. Similarly, the 16.28% of the total area can be used for PV. On the other hand, more than 14 % (Figure 29) consist of the overlapped area that can be used for both RES, due to the smooth topography of the study area.

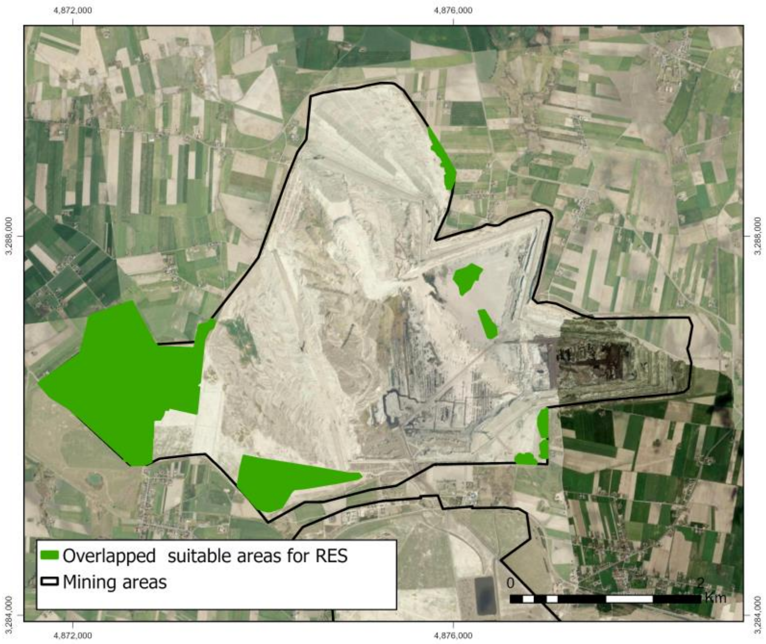

Figure 29. Suitability map that depicting the overlapped areas with green color for both types of RES in Jóźwin mine

Table 17. Total coverage of the Renewable energy sources in the Jóźwin mine

Type of Renewable energy sources	Total coverage (Km^2)	Coverage percentage (%)
Potentially suitable areas for Wind Parks	2.84	19.27
Potentially suitable areas for Photovoltaic Parks	2.40	16.28
Overlapped areas for Renewable energy sources regarding the total extent of the mine	2.11	14.31

ADAMÓW

According the results of the GA, the areas that are suitable for the installation of PV are depicted with yellow color, with the largest coverage concentrated in the central part of the mine (Figure 30). Additionally, suitable areas are also detected along the boundaries in the northern edges of the mine, with a total coverage area up to 2.13 Km2 (Table 18). Regarding, the suitable areas for the WP installation, they largely overlap with the PV areas, with a slight difference in the southern side of the mine, reaching up to 2.13 Km2.

In Table 18, the total coverage of renewable energy sources within the boundaries of the Adamow mine is calculated, where the 'Coverage percentage (%)' column represent the proportion of the mine's total extent that could potentially be utilized for each type of renewable energy source. Particularly the 17.84% can be used for 'Potentially suitable areas' for WP, which corresponds to 2.10 square kilometers of the mine's total area. Similarly, the 18.10% of the total area can be used for PV. On the other hand, more than 15 % (Figure 30) consist of the overlapped area that can be used for both RES, due to the smooth topography of the study area.

Figure 30. Suitability maps for the installation of Renewable Energy Sources (RES) in Adamów mine. The top right map illustrates with yellow color the suitable areas for Photovoltaic parks, the top right map presents with blue color the suitable sites for Wind Parks and the lower map depicts with green color the overlapped areas for both types of RES.

Table 18. Total coverage of the Renewable energy sources in the Adamów mine

Type of Renewable energy sources	Total coverage (Km^2)	Coverage percentage (%)
Potentially suitable areas for Wind Parks	2.10	17.84
Potentially suitable areas for Photovoltaic Parks	2.13	18.10
Overlapped areas for Renewable energy sources regarding the total extent of the mine.	1.85	15.72

KAZIMIERZ

The results of the implemented geospatial analysis (Figure 31) is showing that for the proposed installation of both RES, the suitable areas are very similar in terms of coverage reaching a total coverage up to 2.25 Km2 and 2.00 Km2 (Table 19), respectively.

In Table 19, the total coverage of renewable energy sources within the boundaries of the Kazimierz mine is calculated, where the 'Coverage percentage (%)' column represent the proportion of the mine's total extent that could potentially be utilized for each type of renewable energy source. Particularly the 10.83% can be used for 'Potentially suitable areas' for WP, which corresponds to 2.00 square kilometers of the mine's total area. Similarly, the 12.19% of the total area can be used for PV. On the other hand, 10 % (Figure 31) consist of the overlapped area that can be used for both RES, due to the smooth topography of the study area.

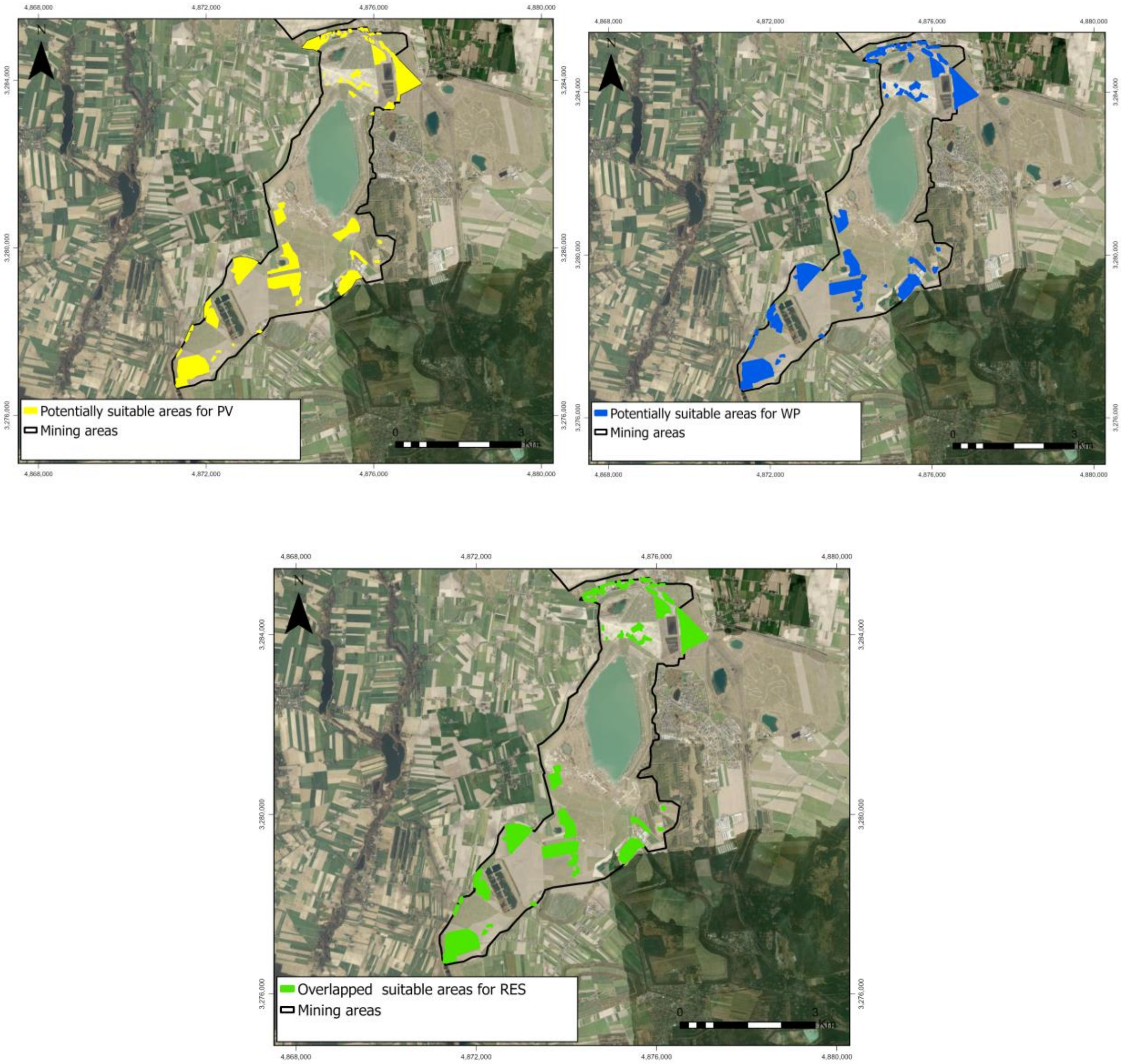

Figure 31. Preliminary suitability maps for the installation of Renewable Energy Sources (RES) in Kazimierz mine. The top right map illustrates with yellow color the suitable areas for Photovoltaic parks, the top right map presents with blue color the suitable sites for Wind Parks and the lower map depicts with green color the overlapped areas for both types of RES

Table 19. Total coverage of the Renewable energy sources in the Kazimierz mine

Type of Renewable energy sources	Total coverage (Km^2)	Coverage percentage (%)
Potentially suitable areas for Wind Parks	2.00	10.83
Potentially suitable areas for Photovoltaic Parks	2.25	12.19
Overlapped areas for Renewable energy sources regarding the total extent of the mine	1.85	10.02

2.4. SUMMARY

The objective of this subtask was the evaluation of selected RES in order to evaluate the produced geospatial and attribute data from the previous section in Western Macedonia (Greece) and Konin (Poland), focusing on potential reutilization options related to Renewable Energy Sources (RES). Specifically, the assessment was implemented by applying scenarios and specific proximity criteria in an effort to identify the potentially suitable areas for the installation of Photovoltaic and Wind Parks by utilizing open sources geospatial datasets, as well as the legislations of every country. Specifically, the open-source geospatial datasets that were used for this analysis related with the elevation, the wind speed, solar radiation and the land cover/land use types of the study areas. Furthermore, an additional scenario was implemented for every study area by calculating the overlapped areas that are suitable for both RES scenarios (Solar & Wind parks). The coverage of each scenario was quantified to enable comparison and evaluation across the study areas, as well as to support preliminary decision-making process.

In the Western Macedonia region, scenarios were implemented in a study area outside the boundaries of the open-pit mines, specifically to the southwest side of the Ptolemaida mine. From the perspective of the PV scenario, the results identified areas potentially suitable for the installation of Photovoltaic parks on the flatter surfaces located on the eastern and the southern sides of the study area. In the WP scenario, the results illustrated that the most potentially suitable areas for the development of Wind parks are on the highest altitudes located on the western of the study area located at the highest elevated regions. The third scenario, which illustrated the overlapped areas of the first two scenarios, indicated that there are small extent regions suitable for both technologies due to the mountainous topography of the selected region.

Summarizing, the PV scenario highlighted that the highest percentage coverage of the study area is more suitable for Photovoltaic parks up to 34%, followed by the Wind parks with a total coverage up to 13.4%.

In the Konin region, scenarios were implemented within the boundaries of the open-pit mines of Jozwin, Kazimierz, and Adamow. Regarding the PV scenarios, the coverage of the potentially suitable areas for the installation of photovoltaic parks is approximately similar across all three study areas, with coverage ranging from 12% to 18% of the total area. Notably, the Adamow open-pit mine holds the highest percentage for RES utilization. From the perspective of the WP scenarios, the Jozwin mine had the highest potentially suitable coverage for Wind Park installation, followed by Adamow, while Kazimierz had the lowest potential. The third scenario revealed an overlap between the PV and WP scenarios in all three mines, with only a small up to 2% in terms of absolute values. Synopsizing and comparing the three open-pit mines, Jozwin has the greatest potential coverage for RES installation, whereas the lowest is identified in Kazimierz open-pit mine. However, it is worth to be noted that Kazimierz has the higher percentage in terms of green transition. Lastly, by comparing the most suitable RES for each mine, both scenarios indicated similar results under the aspect of spatial coverage, but more technical studies and criteria are required for the more detailed evaluation of wind and solar energy potential.

Comparing the renewable energy scenarios, between the Western Macedonia (Greece) and Konin (Poland) regions, interesting meanings arise. Specifically, in Western Macedonia, the potentially suitable areas for PV installation was higher, up to 34% of the total mine area, in contrast to the 12%-18% range observed in Konin's mines. Additionally, the potentially suitable sites for WP installation in Western Macedonia seem to be related due to geomorphological differences, whereas in Konin, the suitability analysis based on ML results within the boundaries of the studied open-pits.

Furthermore, in terms of PV and WP overlapping, Western Macedonia depicted low percentage in areas suitable for both types of parks due to the mountainous morphological characteristics. In contrast, the Konin mines had similar overlapping regions in all three mines with small deviations. However, it should be considered that the implementation of the scenarios in every region was carried out in two different environments (within and adjacent to the boundaries of open-pit mines). However, preliminary scenarios for RES installation require additional criteria, such as detailed technical studies, hydrogeological and geotechnical aspects in order to better assess wind and solar energy potentials as long as other RES categories.

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2.6. LIST OF FIGURES

2.7. LIST OF TABLES