

Planning RES Projects in Exhausted Surface Lignite Mines—Challenges and Solutions [†]

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Abstract: In the context of the complete phase-out of lignite-fired power plants and the corresponding surface mines, the central priority is to ensure a fair development transition for the lignite mining areas. In the context of the installation of renewable energy system projects in the surface lignite mines of Western Macedonia, this paper aims to analyze the challenges for developing photovoltaic projects in areas with different characteristics and to propose solutions for selecting suitable areas, based on corresponding analysis. The investigated parameters cover a wide range of spatial criteria. The results contribute to a pragmatic transition to green energy generation involving a circular economy and sustainable development.

Keywords: photovoltaic RES projects; green energy; repurposing; coal phase-out



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1. Introduction

According to current environmental legislation and relevant scientific investigation, mining land reclamation should gradually follow the completion of mining activity and commence while surface mining operations are still in progress [1]. This reclamation is necessary for both environmental and geotechnical reasons, ensuring suitable landscape architecture and the geotechnical and geochemical stability of mining landforms. The mining reclamation to be undertaken is described, among others, in the environmental impact assessment for the mining operations and the respective decision of approved environmental terms. Relevant projects require strategic planning which takes into account future land uses [2].

The National Energy and Climate Plan (NECP) of December 2019 is the Greek government's strategic plan for climate and energy issues, setting out a detailed roadmap towards attaining specific energy and climate objectives by 2030. The NECP should contribute substantially to the necessary energy transition in the most economically and competitive manner for the national economy. It should also ultimately ensure that Greece stands out as one of the Member States that have adopted ambitious climate and energy objectives through a comprehensive and cohesive program of measures and policies, thus placing Greece at the core of developments in the Energy Union for 2030 and, ultimately, for 2050. A key objective in the context of the new revised government strategy for the NECP is a highly ambitious program for sharply reducing the share of lignite in power generation, i.e., the so-called lignite phase-out, by implementing a relevant front-loaded program in the following decade and completely ending the use of lignite for power generation in Greece by 2028. The NECP sets out the timeframe for shutting down the lignite-fired power plants currently in operation, which will be completed by 2023. The lignite phase-out

plan for power generation in Greece involves adopting integrated programs to support lignite-producing areas in Greece and smooth the transition to the post-lignite era.

According to the NECP, all the Public Power Corporation (PPC) lignite thermal power plants in operation, with a total installed capacity of approximately 4 GWe, are expected to be withdrawn by the end of 2023. In addition, the new Ptolemais 5 plant, which is under construction, is estimated to stop lignite electricity generation by 2028. In this framework, all lignite mines are to be closed in Western Macedonia and Megalopolis, Peloponnese. Thus, a new picture has now been created for the domestic power generation sector regarding lignite production units. As described in the NECP, the installed capacity of new RES projects has been estimated to be 19 GW by 2030, producing 38 TWh yearly, corresponding to 60% of energy produced (over 75% when hydroelectric power plants are included). Furthermore, the corresponding installed capacity of new photovoltaic (PV) projects will comprise about 30% of the RES projects.

According to current environmental legislation and best practice, after mining works are completed, reclamation of the mining areas should follow for environmental and practical reasons, including geotechnical soil stability [3,4]. However, since the PV stations are planned to be developed in the mine landfills, proper soil reclamation is crucial, so that the PV stations can be installed as soon as possible, without the risk of any subsidence or geotechnical instability problems. At the same time, the ground levelling will increase the installed power density of the photovoltaic stations [5,6].

The simultaneous operation of lignite power plants, mines, and related infrastructure, such as belt conveyors, roads, substations, and HV lines, with the development, approval, and construction of PV stations, is an increasingly important area involving both technical and licensing issues. Each of these three functions is governed by a different licensing regime, which must be fulfilled and observed simultaneously, with every action requiring to be considered to avoid any adverse effects resulting from these functions [7,8]. The above framework and the particular characteristics of the areas led to an original approach for developing PV Stations in the areas of lignite mines in Western Macedonia.

This paper aims to analyze the challenges for developing photovoltaic projects in areas of different characteristics and to propose solutions for selecting suitable areas based on corresponding analysis.

2. Materials and Methods

2.1. Study Area

In the lignite centre of Western Macedonia (LCWM), the exploitation of lignite mines by the PPC started in 1957. A total of 1.74 billion tons of lignite had been mined in LCWM until the end of 2020, with total excavations of 8.7 billion m³ and an overall stripping ratio (i.e., waste to lignite) of 4.16 m³/t. After the phase-out of the Amyntaio–Lakkia and Kardina mines during 2020–2021, two mines will be in operation (e.g., Mavropigi and South Field) in the LCWM area until the phase-out of lignite mining operations. Figure 1 shows an overview of the Ptolemais mines in the LCWM.

Since the PV stations are intended to be developed in the mining landfills, mining land reclamation is crucial to minimize subsidence risk. The results should, in practice, support the transition to green energy generation with a circular economy and sustainable development [9–11].

Reclamation works are carried out in parallel with the exploitation of mining resources in areas where mining activities are being completed. Specifically, 18 km² has been reclaimed for forest use in the Ptolemais region and a further 9 km² for agricultural use [12].

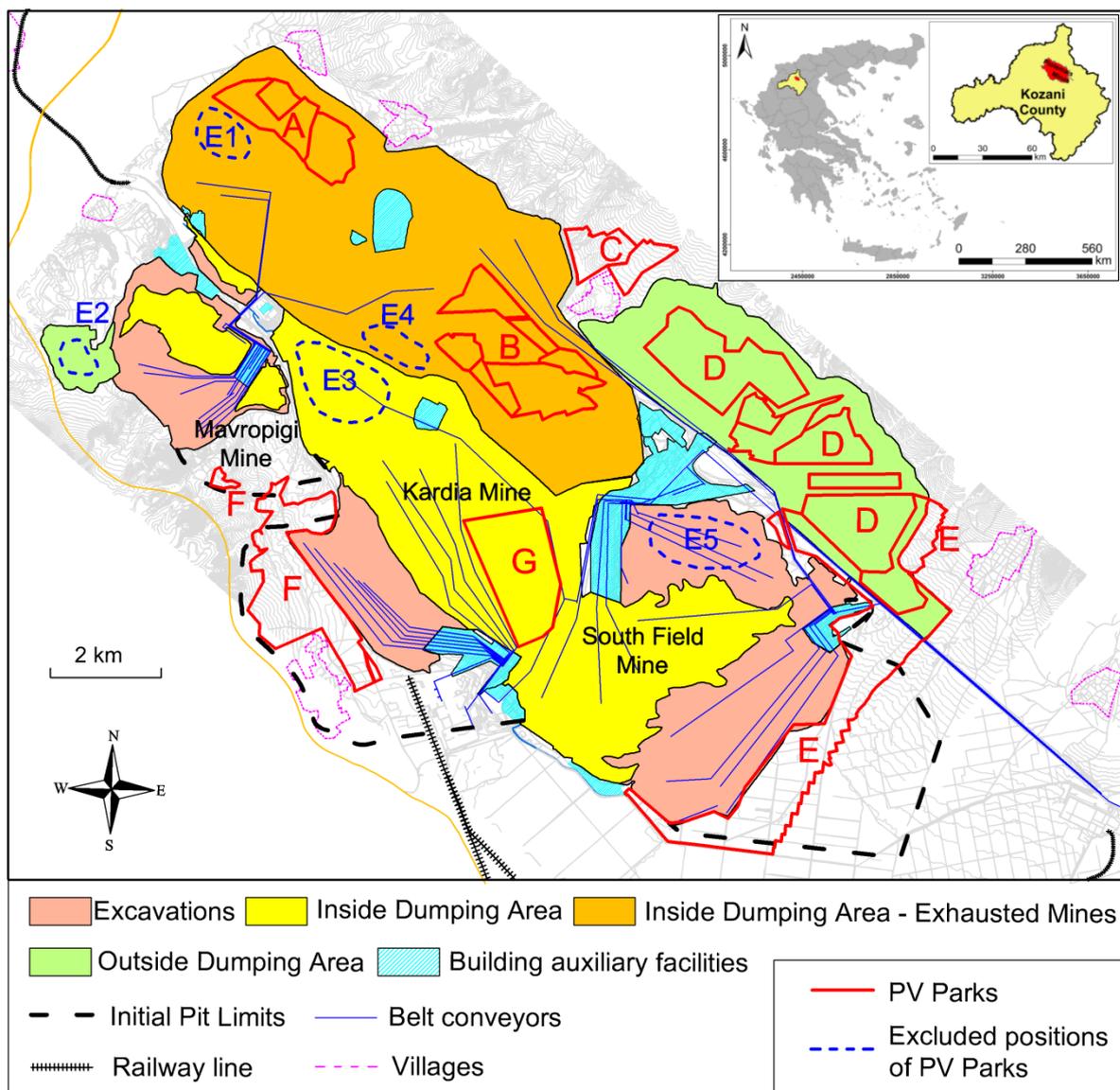


Figure 1. General overview of the study area and locations investigated for PV parks.

2.2. Methods

According to the existing national legislation on the development of RES projects in Greece, specific licensing milestones are tied to the granting of relevant administrative acts/licenses for the projects.

Between December 2018 and December 2019, Public Power Corporation Renewables (PPCR) submitted 19 different applications to the Regulatory Authority for Energy (RAE) for power producer licenses (defined as RES Producer Certificates from May 2020 onwards) for a total capacity of 1.9 GW. At the same time, three projects with a total capacity of 230 MW are under construction. For these 19 projects under development, PV panel installation studies were initially carried out. For these areas, and before the implementation of other studies, an environmental pre-audit was carried out to identify the features of each polygon with respect to licensing issues.

The design of PV panels, and their nominal capacity, were based on topographic studies. The topographic survey data were based on contours generated by drones. At the same time, in situ topographic studies were carried out to identify the flood lines of the streams by synthesis of hydraulic studies. The study mentioned above considered streams, slopes, existing road construction, and the forest maps posted by the local Forest Offices. It

is of note that the forest maps changed while the development and licensing studies of the projects were in progress, resulting in the need to change the original studies.

At the same time, data related to the mining activities for evaluating the geotechnical characteristics of the development areas of PV Stations were used. The evaluation of the areas was based on the applied dumping method, the year of completion, and compilation of a corresponding geotechnical program. Concurrently, the safety distances from the existing trenches for the PV panel installation were estimated. Studies were carried out on the levelling of the areas for the location of PV panels in the areas already reclaimed to maximize the power density of the projects. At the same time, road access assessment was implemented in the areas of development of the PV Stations, with the prerequisite of the optimal possible utilization of the existing road infrastructure of the mines. All the above assessments were incorporated in the environmental impact assessment of the 19 projects under development.

The investigated parameters included: (a) the current land use/cover, (b) the time of the completion of mining works, (c) the slope and orientation of the mining land, (d) the distance from settlements, villages, and populated areas, (e) the proximity to transmission lines and road network, (f) the geotechnical stability, (g) the hydrogeological conditions, (h) the existing infrastructure, and (i) the archaeological areas.

3. Results and Discussion

The main challenges affecting the installation of PVs in the areas of continuous surface mining areas are related to the following issues:

- part of the mining area is active, including excavations and dumping sites;
- some of the reclaimed areas are recent dumping sites;
- the combination of continuous and non-continuous mining methods creates complex geotechnical conditions.

In the framework of the development of RES projects in the surface lignite mines of Western Macedonia, the challenges mainly relate to the optimal utilization of mining land concerning the topography and the technical characteristics of the mining land, the current mining activities, and the alternative land uses.

The areas that were evaluated for photovoltaics installation are reclaimed dumping sites and undisturbed soil. Initially, twelve sites were selected for PV installation. Then, based on the parameters detailed in Table 1, a suitability index was created, ranging from the most suitable (10) to the least suitable (1). The main parameters for the assessment of the suitability index were the land use of the evaluated areas (e.g., undisturbed soil, reclaimed areas, inside or outside dumping areas), the operation period in the case of dumping (e.g., start and completion year, duration of operation, time distance from completion), dump height (e.g., high or low), land availability for the installation of PV (e.g., immediate or future), and the material type of dumping. In addition, other parameters, such as increased slopes, old landslides, water bodies, archaeological sites, required earthmoving works, and suitability priority for other uses, were taken into account for the assessment of the index.

The ranking procedure considered the parameters and the constraints (remarks) for each site. Higher values (9–10) of the suitability index were attributed to the C, E, and F positions due to the undisturbed soils. Moderate values were attributed to reclaimed areas (A, B, D, and G). However, lower values were attributed to the E1, E2, E3, E4, and E5 positions (4, 5, 4, 5, and 2, respectively), for several reasons: some sites were still in operation, requiring earthmoving works, had increased slopes, or were of higher priority for other land uses. After site evaluation, the areas were categorized in seven cases as suitable for PV installation, while the other five were excluded (Figure 1).

Table 1. Suitability assessment of PV park locations.

| Position | Land Use | Dumping Period | Dump Height (m) | Land Availability | Material Type | Suitability Indicator | Remarks | |
|----------|----------------------|-------------------------------------|-----------------|------------------------------------|------------------------------------|---|---------|--|
| A | Reclaimed area | Inside dumping area–Exhausted mines | 1987–2006 | 70–100 | Yes | Clastic and sandy clays, marls | 7–8 | - |
| B | Reclaimed area–Dumps | Inside dumping area–Exhausted mines | 1979–2019 | 80–130 | Yes | Clastic and sandy clays, marls, sands | 6–8 | • Occasionally reclaimed forest land |
| C | Undisturbed soil | - | - | Yes | - | - | 10 | - |
| D | Reclaimed area–Dumps | Outside dumping area | 1980–2019 | 30–120 | Yes | Clastic and sandy clays, calcareous marls, sands, gravels | 5–7 | • Occasionally reclaimed forest land • Increased slope • Old landslide |
| E, F | Undisturbed soil | - | - | Yes | - | - | 9–10 | • Archaeological site • Water bodies |
| G | Dumps | Inside dumping area | 2006–2019 | 100–130 | Yes | Clastic and sandy clays, marls | 5–6 | • Recent waste dumps |
| E1 | Dumps | Inside dumping area–Exhausted mines | 2002–2017 | 90–120 | After the end of mining operations | Clastic and sandy clays, marls | 4 | • In operation • Increased slope |
| E2 | Dumps | Outside dumping area | 2011–2019 | 20–50 | Yes | Conglomerates, gravel and marls | 5 | • Suitability priority for other use |
| E3 | Dumps | Inside dumping area | 2009–2018 | 40–60 | After 2023 | Clastic and sandy clays, marls | 4 | • In operation • Required earthmoving works • Suitability priority for other use |
| E4 | Dumps | Inside dumping area–Exhausted mines | 1989–2001 | 40–80 | Yes | Clastic and sandy clays, marls, sands | 5 | • Suitability priority for other use |
| E5 | Excavations | - | - | After the end of mining operations | - | - | 2 | • In operation • Increased slope • Suitability priority for other use |

4. Conclusions

In the present study, an innovative method of studying the areas of lignite mines to install PV projects is presented. It represents a pioneering approach to the rehabilitation of lignite mines, given the simultaneous development of RES projects and the operation of the mines and lignite power plants. The development of these PV projects is compliant with the existing environmental legislation. The investigated PV projects were in low-risk areas regarding various other restrictive parameters (e.g., agricultural land of high productivity, settlement limits, archaeological and critical cultural sites, etc.). The main nominal capacity resulted from energy simulations using premium quality and highest efficiency equipment, taking into account the characteristics of the soils and dumping sites, the slopes, the existence of streams and forest areas, and the existing infrastructure of the mines.

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