sustainability

MDPI

Article

Evaluation of Strategies for the Sustainable Transformation of Surface Coal Mines Using a Combined SWOT–AHP Methodology

Philip-Mark Spanidis [1], Christos Roumpos [2,*] and Francis Pavloudakis [3]

[1] Division of Project Management, ASPROFOS Engineering, 176 75 Athens, Greece
[2] Department of Mining Engineering and Closure Planning, Public Power Corporation of Greece, 104 32 Athens, Greece
[3] Mineral Resources Engineering Department, School of Engineering, University of Western Macedonia, 501 00 Kozani, Greece
* Correspondence: c.roumpos@dei.gr; Tel.: +30-697-979-9291

Abstract: The sustainable transformation of surface coal mines aims to recover geoenvironmental and socioeconomic factors (ecosystems, landscape, soil, water, employment, etc.) related to extractive operations. The transition to sustainability starts when a mine enters the ageing/closing phase and includes large-scale technical activities for repurposing the mined sites. Moreover, circular economy practices and methods are introduced for efficient and socio-environmentally friendly use of mining wastes and non-exploited resources. The selection of a strategy for the sustainable transformation of a mine constitutes a complex decision-making framework presenting various practical problems. This paper provides a critical analysis concerning the definition of the transformation problems and suggests a decision-making methodology for the selection of a strategy for sustainability with a case study of a closing surface lignite mine in Greece. The methodology combines (a) a strengths–weaknesses–opportunities–threats (SWOT) analysis of the factors of critical importance for the evaluation of alternative strategies, and (b) the analytical hierarchy process (AHP) applied for the quantification and use of these factors for the selection of the most advantageous strategy. In this context, it is based on expert judgement. The results indicate that the proposed analysis can be used as a practical decision-making tool to resolve complex problems related to the mine closure and post-mining issues.

Keywords: continuous surface mining; circular economy; strategic framework; post-mining; reclamation

Citation: Spanidis, P.-M.; Roumpos, C.; Pavloudakis, F. Evaluation of Strategies for the Sustainable Transformation of Surface Coal Mines Using a Combined SWOT–AHP Methodology. *Sustainability* **2023**, *15*, 7785. https://doi.org/10.3390/su15107785

Academic Editor: Marc A. Rosen

Received: 9 February 2023
Revised: 4 May 2023
Accepted: 6 May 2023
Published: 9 May 2023

1. Introduction

Surface coal mines are usually extensive industrial complexes where vast coal volumes are exploited to feed corresponding power generation plants. The mining activities cover tens of square kilometers, and the extracting activities follow site-specific exploitation plans [1]. However, the impacts from the coal exploitation might affect the ecosystems, water resources, landscape, landforms, soil fertility, and air quality, unless appropriate mitigation measures are implemented [2,3].

The life cycle of a surface coal mine is divided into certain phases, including (a) land use planning and exploration, (b) development, (c) maturity, (d) ageing/closure, and (e) post-mining reclamation [1].

Once a mine moves from late maturity to the ageing/closure phase, the mining managers prepare mine-specific closure plans [4]. Customarily, these plans constitute the basis of interventions for the reclamation of disturbed lands and repurposing of land uses [3]. In addition, reclamation activities are drivers towards an environmentally friendly and socially acceptable perspective [5]. In other words, the post-mine reclamation and restoration frameworks are developed based on systematic interventions.

The concept of sustainable development was introduced by Brown [6], who investigated managerial solutions for balancing renewable and non-renewable resources in energy production systems. The definition of sustainable development as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" has been recommended by the World Commission on Environment and Development (WCED) [7], and it is broadly mentioned in the literature, with some content-wise alternations regarding the views of sustainability in industry, economy, and technology [8–11]. In the mining industry, sustainability is related to the environmental impacts of mining and the minimization of the footprint of its activities throughout the mining cycle [12]. In this context, mining sustainability can be seen as a strategic process for transforming and repurposing the mined sites into a new land use system of higher environmental and social value. On this basis, new models inspired by advanced technologies and best practices can be developed, enhancing the role of the main pillars of sustainable development: society, environment, and economy [13–15].

In recent years, many countries have paid much attention to the sustainable transformation of surface coal mines as a bundle of policies for minimizing the carbon footprint and reducing the environmental impacts caused by long-term and intensive production [16,17]. The trend for redirecting the policies from primary energy production to greener and environmentally neutral technologies and solutions worldwide provides the basis for the sustainable transformation of mines. Thus, in the USA, Germany, UK, Greece, Australia, Czech Republic, Poland, South Africa, and several mines in China [18–25], the transition of coal mines to sustainability constitutes a governmental policy and instrument for reformulation of the energy markets. A broad spectrum of technological solutions and methods for "greening" the post-mining sites, such as reclamation, water treatment, removal of toxic substances from the soil dumps and water, stabilization of slopes, landscape and landform restoration, and reforestation and replantation are being widely applied in the sustainable transformation of ageing/closing mines [3].

A sustainable mine transformation proposal must be based on a situational analysis with appropriate techno-economic and socio-environmental studies to support the feasibility of the transformation project. The situational analysis is the background against which the most promising sustainability strategy can be evaluated and applied. However, strategy evaluation is a multidisciplinary, costly, and time-consuming decision-making task. Moreover, some factors related to specific characteristics of the mining operations lead to a relatively complex and dysfunctional framework until the final decision for the sustainable strategy is made. These frameworks include conflicting views of social groups and stakeholders on which land use model or restoration method is the most practical, as well as budgetary and funding limitations, reactions to the expected loss of livelihood and income due to the ceasing of extractive activities and logistics, and the introduction of CE practices/methods not familiar to local societies.

The objective of this paper is twofold: (a) to investigate the problems related to the sustainable transformation of mined sites when mine operations stop or steadily decline, and (b) to advise on a managerial tool suitable and efficient for the analysis of the criteria or factors on which the process for the evaluation and selection of a sustainable strategy in the mining industry can be planned and executed.

The paper is structured as follows. Section 2 is a literature review on aspects and views of the sustainable transformation of mines. Section 3 analyzes the problems in the decision making for strategy selection and addresses critical research questions. Section 4 provides the methodology suggested for the strategy selection, which is a combination of (a) SWOT analysis used for the identification of the evaluation factors and subfactors and (b) AHP used for the quantification of the evaluation factors and the calculations for the selection of the most promising transformation strategy from a set of alternatives. The combined SWOT/AHP method is based on expert judgement; it is applied in a case study of a Greek lignite mine that is entering the closing phase. Section 5 discusses the results from the application of the suggested methodology. Finally, Section 6 presents the conclusions of the work and addresses topics for improvement and further research.

2. Literature Review

2.1. Sustainable Transformation of Mining Technical Systems and Operations

The technical system of a surface mine refers to the mining equipment utilized in extractive activities and processes [26,27].

The key role of this system in the sustainable functioning and transformation of a mine was demonstrated by Rakhmangulov et al. [28]. They identified the crucial problem of the absence of clearly formulated principles for the introduction of sustainability in the mining industry and proposed an AHP methodology for the quantitative investigation of parameters and indicators which effect the main interventions and changes required for the sustainable performance of the MTS (e.g., energy saving, avoidance of soil and water pollution, etc.). Furthermore, best practices, technologies, innovations, and solutions reported in academia and industry for the sustainable transformation of mines were analyzed by Aznar-Sanchez et al. [29] from economic, environmental, social, and technological viewpoints. Pavloudakis et al. [13] presented the context of sustainability in mines as a multidisciplinary project enabling the transition from the linear production model to the 3R (reduce, reuse, and recycle) model. Furthermore, circular practices for sustainability in mining were introduced by Voncken and Buxton [12], who proposed the use of technologies for the blending of acid-generating and acid-consuming materials, aiming to minimize acid mine drainage (AMD) effects in the mine wastes and to benefit from the economic value of mining. Young and Baretto [5] described a context for the adaptation of CE techniques and methods in the mining systems of Canada and recommended several key principles for the sustainable transformation of mines, such as redesign of mining operations based on zero waste, low carbon, and social acceptance provisions. Mayes et al. [30] suggested a circular sustainability framework for better use of former mining lands, emphasizing the recovery of resources (metals and minerals, aggregates, heat, and power), carbon storage, ecosystem enhancement, and societal benefits. Vo et al. [31] introduced a new perspective on the reusability of coal mining wastes and geomaterials as raw materials in the construction industry, especially in the production of concrete and cementitious composites for civil engineering applications. The Society of Mining Professors [32] provided an overview of sustainable mining practices, including water management, mine waste management, and energy efficiency. Chen et al. [25] analyzed the strategic purpose of sustainability in mining and discussed the problems and difficulties of the "green transition". As a solution, the introduction of green innovations and construction methods was recommended. Finally, in the work of Spanidis et al. [33], knowledge gaps were introduced as knowledge deficiencies affecting mining operations and the implementation of sustainable solutions. Knowledge gaps result from organizational changes, retirement of expert personnel, poor updating of mines' technical archives, limited understanding of lessons and empirical evidence from long-term mining operations, and lack of scientific evidence on critical aspects.

2.2. Environmental and Ecological Restoration

In post-mining frameworks, the restoration of environmental factors is an issue of primary concern. Sloss [34] reported on the criticality of environmental impacts and the detrimental effects of mining from the leaching of acid trace elements and discarded materials. He suggested reclamation as an appropriate method for mined land environmental and ecological recovery. Imboden and Moczek [35] proposed a concept for managing and recovering biodiversity and the ecological functionality of the Hambach mine in Germany. In this framework, they provided an analysis of the social and stakeholder engagement issues and the risks and opportunities of the relevant framework for the transition to sustainability. Tischew et al. [36] introduced the problem of knowledge limitations regarding the successional and near-natural restoration process and the interactions between them. They also addressed the importance of in-depth analysis of the biological and ecological background and the geomechanical characteristics of the mined lands to adopt the most suitable restoration solution. The restoration of a closing coal surface mine in the Appalachian region (US) was investigated by Fields-Johnson et al. [37], focusing on the soil grading and seeding effects and the techniques used for native tree replantation. Chuman [22] described the restoration practices applied in mines of the Czech Republic and provided a critical analysis of technical reclamation versus restoration methods based on natural processes. He also recommended that mine organizations prepare efficient reclamation and closing plans, in which the restoration frameworks will be properly supported by detailed investigation as a part of an integrated situational analysis of the area-specific ecological and biological factors. McCullough [38] reported key mine closure lessons from Australia and issues of geoenvironmental importance for sustainable transformation, emphasizing AMD of mining waters and soils, the quality of remaining ore, the soil erosion effects, and the critical problems of slope stability. Yu [39] described the environmental development in coal mining areas in southwest China since 2000 and demonstrated cases where "China's western development strategies (WDS)" and measures taken for the sustainable transformation of mines have been successfully carried out. Spanidis et al. [40] presented problems deriving from evaluations of a low-risk reclamation strategy selection in mines entering the ageing/closing phase and proposed a decision-making methodology based on the AHP to resolve the technical and managerial dysfunctions of the strategy evaluation work. Araya et al. [41] suggested a framework for reprocessing mine tailings in Chile to produce and commercialize critical raw materials (CRMs). The framework, based on real-options analysis (ROA) and sensitivity and uncertainty analysis, was applied to assess the profitability of using mine tailings as a source of CRMs in the mining industry of Chile. Xu et al. [42] investigated the problems of landscape changes in the Pingshuo opencast lignite mine in China. They proposed a methodology based on the minimum cumulative resistance (MCR) model to perform an integrated landscape ecological risk assessment. Kivinen [43] analyzed the restrictions and hazards to be properly managed in the sustainable redesign of the land use complexes in post-mining sites. Mayes et al. [30] suggested introducing CE practices for the legacy waste management of post-mining sites for the benefit of resource recovery, carbon storage, ecosystem enhancement, and societal benefits from the change in land use in reclaimed areas. Finally, Vo et al. [31] presented a review of the geochemical, geotechnical, and structural engineering properties of coal mining waste geomaterials and proposed the valorization and upcycling of these materials for the replacement of aggregates and binders in the preparation of concrete and cementitious composites.

2.3. Stakeholders, Society, and Economy

Stakeholders, society, and the economy play a crucial role in accepting and implementing sustainable transformation projects [32]. In the 12th Chapter of the PMBOK® Guide-25th Edition [44], stakeholders are defined as "*individuals and organizations who are actively involved in the project, or whose interests may be positively or negatively affected as a result of project execution or successful project completion*". Stakeholders have a particular interest in the sustainable transformation of a mine as it relates to (a) the ceasing of activities crucial for the livelihood of local municipalities and communities, and (b) development of new markets, supply chains, and businesses governed by practices/methods of CE [5]. The literature shows that researchers pay much attention to understanding the role of stakeholders, affected societies, and the economic impacts anticipated in the period of mine transition. Haney and Shkaratan [45] presented a World Bank study on the social impacts of mines closed in Romania, Russia, and Ukraine to describe the effect of mine closure and evaluate the various mitigation efforts used by governments in such cases. The authors used quantitative and qualitative methods for the necessary data collection and processing, based on interviews with national, regional, and local experts and members of the affected populations. Swart [46] described the legislative framework of mine closures in South Africa and investigated the role of stakeholders with opinions on the public participation processes and decisions made for the objectives and plans of mine rehabilitation projects. Marais and Atkinson [47] provided an overview of the socioeconomic consequences and lessons from mine closures in South Africa and presented the legislative tools used to mitigate impacts on the survival and livelihood of local societies. The report of COALTECH [48] was the background material for analyzing the socioeconomic context of coal mine closures in South Africa and introducing the viewpoint of transition to sustainability after the expiring of the ageing/closing phase of mines. This report provided an analysis of the importance of stakeholder engagement, the socioeconomic and environmental goals of mine closing, the consultation and empowerment required, and the challenging perspectives and principles for the sustainable transformation of the mined sites. Pavloudakis et al. [2] recommended a framework for effective communication between the proponents and the supervising authorities of a post-mining project. The framework enables the lawful handling of various environmental and socio-economic issues and the minimization of risks of political damage, financial loss, or cancellation of the project itself. McCullough [21] and Swanson [49] stressed similar problems, emphasizing the restoration of pit lakes in mines. They underlined the significance of stakeholder and community opinion(s) on any aspect of transformation as a constituent element for the planning and execution of a transitional project. Kivinen [43] investigated the situation of post-mining sites in Finland with a statistical analysis using data from closed mines. The author addressed the decision-making problem of how the most suitable project and/or intervention model for sustainability can be evaluated, and presented options for solutions to redesign land use. Imboden and Moczeck [35] analyzed the biodiversity restoration framework and the interactions between biodiversity, ecosystem components, and human well-being in a case study of the Hambach lignite mine in Germany. They noted the contribution of stakeholders involved with the restoration process at a global, regional, and local level, the general public, special interest groups, and NGOs in the restoration actions and decisions. The work of the Society of Mining Professors [32] identified critical aspects for consideration in transitions of post-mining areas to sustainability, one of which is the role of clear, respectful, and democratic dialogue among stakeholders. Chen et al. [25] demonstrated the "green" or "ecological" mining solutions implemented in 661 restored mines in China to reform the traditional, and particularly harmful, practices of mining to achieve the sustainable development of resources, environment, and the economy while increasing the social benefits. Pactwa et al. [23] referred to the "second life" of post-mining sites and infrastructures from the viewpoint of sustainable transformation. They analyzed the problems of the employees working in mining-related enterprises and suggested that the land use change focus on other activities, such as tourism (see also [50]). Finally, Young and Baretto [5] analyzed the "creation of social value" and "well-being of societies" and presented viewpoints on how CE practices and methods may enhance the sustainable transformation of mines.

2.4. Policies and Initiatives

In recent years, a remarkably increasing trend of declining coal consumption for electricity generation worldwide, especially in EU countries, has been noted [51]. The causes of this trend are the competitive development of carbon-neutral technologies (hydrogen, solar, and wind systems) and the distribution of natural gas as an environmentally friendlier and low-cost fossil fuel [33,52]. In addition, numerous mines are being downscaled or terminating operations worldwide. As a result, the closing mines are transforming into sustainable land use systems, while new technologies and supply chains for the valorization and commercialization of mining wastes and unexploited mineral resources are being developed [5].

Various policies and initiatives (regulations, directives, legal instruments, schemes of collaboration, best available practices, and contexts of knowledge exchange) are coming into force to set up the context of repurposing the decommissioned surface mines into sustainable land [5,13,33,48,53–57].

Furthermore, many partnerships, innovative programs, projects, and support actions enhance sustainability and circularity in post-mining frameworks [58]. The objective of these initiatives is the coordination of international efforts towards sustainable development and reverse logistics.

3. Problems and Research Questions

The sustainable transformation of ageing/closing mines is challenging, time-consuming, and complex. It requires investigations involving experts and scientists from multiple fields of science and technology (known as subject matter experts (SMEs); see also [44,59,60]), effective planning and coordination, and well-documented proposals. However, some critical problems need to be identified and adequately managed when the project feasibility study and execution plan are under preparation. The most critical of them are the following (in alphabetic order):

(a) CE and Supply Chain Model: The lack of clear and straightforward principles of sustainable transformation in the mining industry causes uncertainties. The selection of a CE model is difficult since the ecological, geoenvironmental, and socioeconomic characteristics are different from one mine to another. In addition, the constituent parts of a sustainable strategy are issues to be considered under the limitations of space availability and the new land use system.

(b) Complexity: By its nature, a sustainability project requires multidisciplinary and multitasking management, since numerous stakeholders, consultants, and scientific experts must be involved in various activities and work interfaces. It constitutes a complex and crucial managerial problem of high importance, since the project managers must identify and describe the roles and allocate responsibilities of any involved party. In this context, a long-term and resource-consuming analysis needs to be carried out to answer the following: by whom, for what, how, when, within which priority and authorization, and to which extent must the scope of the work each party undertakes be performed.

(c) Decision Making: The transformation strategy is a priority issue of high criticality for the organization, planning, and execution of the sustainability project. However, strategy selection results from a decision-making process presenting difficulties, such as the evaluation of the method/tool to be applied, the organization and execution of the evaluation workshops, the analysis of the evaluation results, and the presentation and disclosure of the results to stakeholders. A decision-making failure that must be avoided is the selection of a less effective, inefficient, or low-reasonability strategy that may insert risks into the transformation project. For this reason, the participation of SMEs in the evaluation process is valuable and indispensable.

(d) Ecological Restoration: It is an uncertain issue, as the interaction mechanisms between the near-natural and the artificial restoration actions need further scientific substantiation. Even more important is the restoration method to match the mine-specific geoenvironmental and ecological characteristics. Therefore, the decision for the ecological restoration method is a very critical issue.

(e) Finance and Bankability: The estimation of the transformation budget is another problem embodying uncertainties. It is related to several circularity scenarios that can be examined and various assumptions that might be recommended for explaining to lenders and funding executives that the techno-economic profile of the project is robust and, therefore, the project is bankable. Moreover, it must be proven that the opinions of societies and stakeholders have been considered in the budgetary estimations and formulations of the alternative strategies.

(f) Knowledge Gaps: They are related to the understanding of how and under which conditions knowledge requirements and background information of a mine transformation project can be controlled and managed. This issue must be considered by mining project managers involved with the scoping, planning, organization, and execution of the transformation project, so that synergies for knowledge and technology transfer (KTT) or technical consulting on sustainability aspects are established, if so required.

(g) Legislation and Permitting: The understanding of the legislative framework and any other initiatives related to sustainability, requires an in-depth analysis of the legal content and limitations in force, as well as knowledge of the permitting procedures, protocols, and practices of public agencies. Moreover, a new environmental and social impact assessment must be submitted to demonstrate that the new land use system and the content of the sustainable activities are feasible and compliant with the law. Experience shows that, in most countries, the permitting and licensing of a new sustainable land use system is a complex and time-consuming task, which may be a reason for stopping or delaying transformation projects.

(h) Prescreening of Engineering Solutions: The reforming of post-mining lands requires engineering solutions and optimization for the landscape and landform restoration, redesign of land use, soil improvement, slope stability measures, rehabilitation of defective roads/accesses, infrastructures and facilities, and appropriate site development plans enabling the circularity operations to begin. The engineering solutions must be based on situational analysis and agile, to (a) ensure that circular economy activities are technically feasible, and (b) enable adaptability of different practices and methods of sustainability.

(i) Stakeholder Engagement and Societal Issues: Stakeholder engagement is a participatory process based on a creative and open dialogue between mining companies and interested parties (authorities, communities, municipalities, regional agencies, central government, NGOs, ecological societies, interested groups, and independent bodies). This process aims to exchange opinions and to enable the shaping of proposals for the transformation project and the CE model to be adopted. However, the organization and management of the participatory process are complex, dysfunctional, and time-consuming, as each stakeholder has their own agenda of policies and priorities for the content and actions of sustainability.

Based on the above-described problems, a transformation project must be structured and governed by a well-grounded, feasible, and realistic strategy. However, the context of strategy selection has multiple interpretations, since parties from various disciplines and with different agendas and priorities are involved in the evaluation framework. Moreover, the scientific opinions on sustainability strategies differ from one team of interest to another. Finally, the multidisciplinary nature of sustainability and the need for a spherical scientific investigation introduce several critical research questions, which are the following:

RQ-1: Which method/tool is suitable for the identification of alternative strategies for a project on a mine's transformation to sustainability?

RQ-2: How can the advantages and disadvantages of each strategy be assessed?

RQ-3: How can the opinions of stakeholders and the knowledge of SMEs be aggregated, synthesized, and applied to evaluate the alternative strategies?

RQ-4: How can the evaluation process be performed by an effective and mathematically consistent method for the quantitative evaluation of alternative strategies for sustainability in ageing/closing or already closed mines?

4. Materials and Methods

4.1. Suggested Methodology

The suggested methodology is applied in a case study that evaluates alternative sustainability strategies for a Greek lignite mine entering the closure phase. The main purposes of the adopted methodology are analyzed as follows:

(a) Each strategy has advantages and disadvantages, which can be interpreted as evaluation factors. Some of these factors are internal and depend on the performance capabilities or the deficiencies of the mining company. Some other factors are external and must be effectively managed by the mining company to minimize risks and maximize new business opportunities, so that the transformation project can be proven beneficial from social, environmental, and economic points of view. The authors recommend the SWOT analysis as a business and management tool appropriate for identifying and evaluating several alternative project strategies for sustainability in a particular mine. The SWOT factor analysis reflects the qualitative function of the methodology.

(b) The SWOT analysis is proposed in combination with the AHP method for establishing the relative importance (weight) of each evaluation factor/subfactor of the SWOT analysis. First, the factors and subfactors take a specific numerical value, and then they are introduced in the calculations for the ranking of alternative strategies. The AHP reflects the quantitative function of the methodology.

(c) As already mentioned, the role of SMEs is crucial for the decision-making framework. The combination of SWOT/AHP methods provides the basis for a creative aggregation of knowledge, empirical evidence, and various judgements and opinions expressed on sustainability in an ageing/closing mine. The SMEs may take various opinions from stakeholders, interest groups, or authorized individuals in the evaluation activities, introduce this information in the SWOT analysis, and, in the form of numerical data, use it in the AHP calculations. The SME role and the quantitative synthesis of the opinions collected reflect the participatory function of the methodology.

4.2. The Combination of SWOT and AHP Methods

The SWOT analysis is widely used in strategic management research [61] and was introduced in industry and academia in the early 1960s. As a method, it investigates the internal factors, known as strengths and weaknesses, and the external factors, known as opportunities and threats, which influence an organization, an industrial service, a plan of action, or a project [62,63]. The internal factors are within the control of a mining organization, but the external factors are out of the organization's control and care. In the context of sustainable mine transformation, the SWOT method focuses on analyzing factors that influence the transformation project. SWOT analysis results help to attain support for mining managers and decision-makers. The environmental and social benefits from the restoration and reclamation activities may be considered project strengths, while weaknesses may refer to the complexity of a transformation project and the knowledge gaps it should entail. Market dynamics due to the development of CE methods/practices may be considered opportunities, and the opposition of society, the potentially irreversible environmental impacts, financial/investment limitations, and permitting delays may be considered threats (or risks).

The SWOT analysis is applied in two steps. First, a situational analysis of the mine and the strategic sustainability framework is carried out to identify the evaluation factors and subfactors. The evaluation team (SMEs and authorized decision-makers) identifies four (4) groups of mine-specific evaluation factors and subfactors in the form of well-defined sets of strengths, weaknesses, opportunities and threats. The second step is identifying the alternative strategies using a bi-dimensional matrix known as TOWS/SWOT [64]. In this matrix, the horizontal entries refer to internal factors, and the vertical entries refer to external factors which influence the strategic analysis. Each strategy is displayed in the matrix position that better reflects the influence of the evaluation factors. This way, four (4) combinations of strategies are obtained: SO/maxi-maxi, WO/mini-maxi, ST/maxi-mini, and WT/mini-mini.

The SWOT analysis, however, presents shortcomings when applied as a stand-alone evaluation tool. First, SWOT cannot provide numerical results. Subsequently, the effect of the SWOT factor/subfactor on each alternative strategy is likely determined by consensus among the SMEs, resulting in low objectivity. Second, all factors are considered of equal influence, affecting the evaluation quality and decision to be taken [65,66]. For this reason, SWOT analysis is mainly recommended in the literature as a method to be hybridized with the AHP [63], and for this reason, it is also referred to as the "A'SWOT" method [67].

The AHP is a groupware decision-making method based on multi-criteria analysis, widely developed in academic research, industry, manufacturing, finance, business, and project management [68]. The method is a simple and easy problem-solving tool that is well understood and does not require complex or costly software [69,70]. AHP is structured in a hierarchical model synthesizing the decision-making problem goal, the evaluation criteria, and the alternative solutions [71,72], enabling evaluators to express and transform their knowledge, professional experience, and judgements, in the form of numerical data. The evaluators perform a series of pairwise comparisons to construct reciprocal matrices and to define the relative weight of factors and subfactors and the performance of each alternative with respect to each of these factors/subfactors [73–75]. The quantification of the experts' opinion(s) is carried out via planned workshop(s), brainstorming meetings, semi-structured interviews, filling out structured questionnaires, or a combination(s) of these data collection methods.

4.3. Expert Judgement

A team of experts was engaged (SMEs, sustainability, and stakeholder engagement specialists) to provide support on the following aspects of the methodology:

- Situational analysis of the mine characteristics (geoenvironmental, ecological, and social)
- Understanding the legislative and regulatory framework for the CE practices and methods in post-mining sustainable transformation projects
- Analysis and definition of SWOT factors
- Formulation of alternative strategies and construction of the TOWS/SWOT matrix
- Pairwise comparisons in preparing the input data for the AHP calculations
- Evaluation of a strategy's performance with respect to each factor/subfactor of the SWOT/AHP method
- Construction of the strategy evaluation matrix
- Review of the methodology outputs and results (pros and cons) and lessons learned

The evaluators' team consists of seven (7) experts with an adequate scientific background and long-term professional experience in lignite mines and sustainability management. The team members' qualifications are as follows:

- (Ex1): Mining Operations Manager—PhD, MSc, MEng.
- (Ex2): Lignite Mine Site University Professor—PhD, MSc, MEng.
- (Ex3): Energy Sector Project Management Expert—PhD, MSc, MEng.
- (Ex4): Socioeconomic and Sustainability Senior Expert—MSc.
- (Ex5): Public Official with expertise in sustainability and permits—MSc.
- (Ex6): Permitting and Legislation Engineer—MEng.
- (Ex7): Ecology Expert—PhD, MSc.

5. Case Study

5.1. Project Description

This project of mine land repurposing and transformation into new land uses refers to a complex of four surface lignite mines, with the main continuous mining equipment suitable for multi-seam deposits, where the development of surface mines commenced in 1970 (Figure 1).

The exploitable reserves of three of the mines were exhausted in 1994, 2012, and 2019. As a result, the mining activity is concentrated in a mine located in the southern part of the basin. Within the boundaries of the lignite basin, only one of the two power plants is still in operation, with a capacity of 300 MW. The remaining life of the power plant is 2–3 years, and the only mine in operation has been planned to cover the lignite production demand till the phase-out of the power plant.

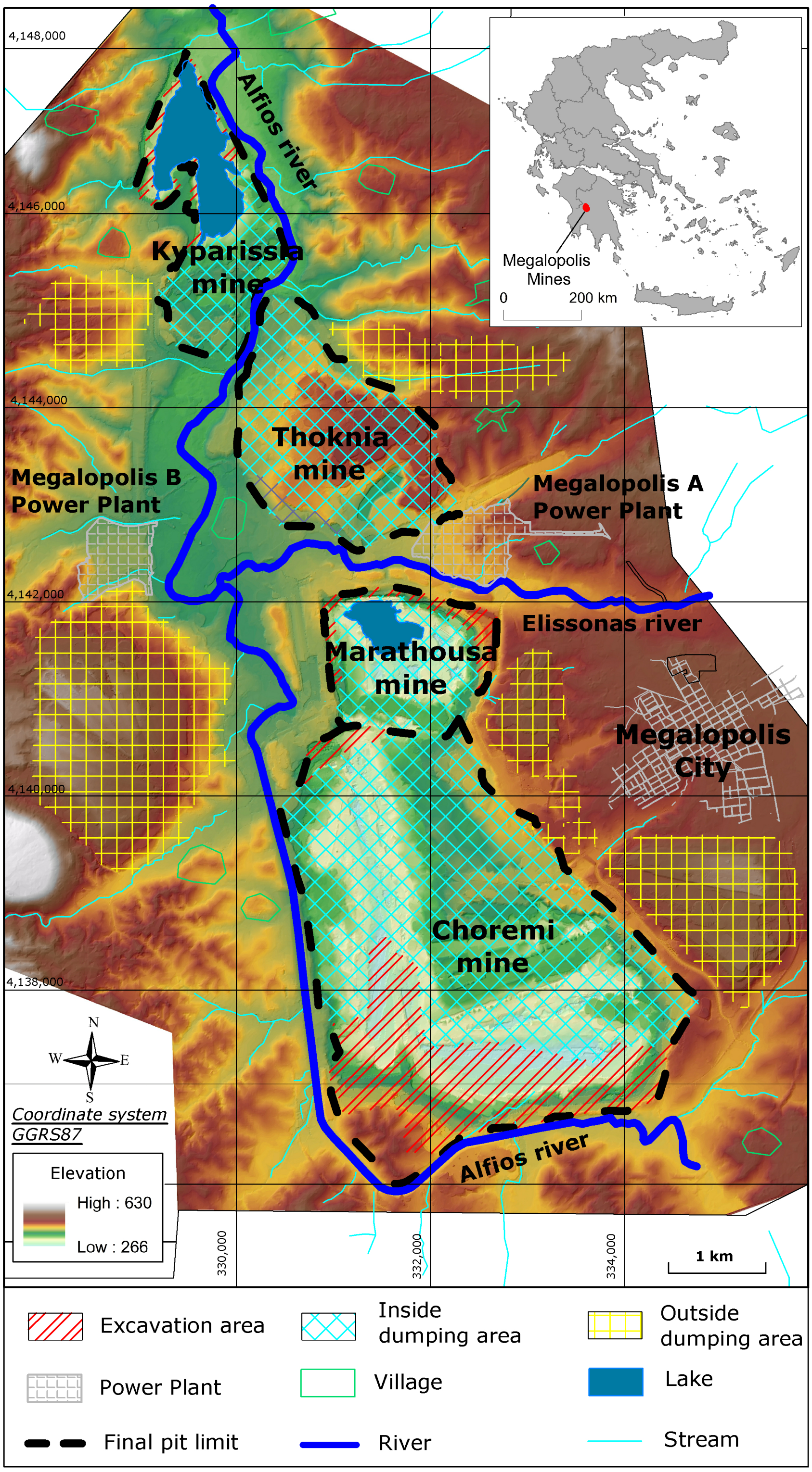

Figure 1. General overview of the surface mining area under investigation.

The outside waste dumping areas were completed many years ago. Therefore, they are suitable for several land uses, depending on the spatial variation of geotechnical, geometrical, and other characteristics. The main previous categories of land use in the basin included agricultural and forest areas, while the peripheral slopes of outside dumping areas have already been reclaimed as forests. On the plateau of some dumping areas or suitable prepared land, the construction of photovoltaic parks has been planned. Within the framework of the present work, strategies for transforming the other mining areas into sustainable land uses and future activities are investigated.

5.2. Management of the Evaluation Process

A one-day workshop (WS1) was carried out with the participation of SMEs aiming to organize and set up teamwork management to evaluate the post-mining sustainable strategies. The critical issues discussed were setting the evaluation goal, the scope and schedule of the evaluation tasks, the objectives of the sustainable transformation, the rules of opinion exchange and questioning among SMEs in the participatory dialogue, teamwork coordination, the rules of confidentiality, the extent to which the SWOT factors and sustainability strategies will be investigated, the quantification of opinions and judgements, and the mathematical processing of the data to be used as inputs in the evaluation calculations. For this reason, introductory training for SMEs was conducted on theoretical and practical aspects of the SWOT/AHP method. In addition, it was agreed to conduct two more one-day workshops: (a) WS2 for the qualitative analysis and identification of the SWOT factors/subfactors and the construction of the TOWS/SWOT strategic matrix, and (b) WS3 for quantification of the SWOT/TOWS analysis, processing of the data obtained, and ranking of alternative strategies.

5.3. Analysis and Definition of SWOT Factors and Subfactors

In WS2, exchange of opinions and brainstorming among SMEs on various options for the transformation project were carried out. The workshop was organized into two parts: (a) a review of background information collected from the situational analysis of the mine (geology, landscape, water and soil contamination status, waste volumes, landscape and topography, ecological and socio-environmental considerations, etc.), and (b) identification of SWOT factors in four (4) discrete sets, S, W, O, and T and grouping of subfactors into the following lists.

Strengths—(S)

S1 Transformation of heavily affected mine sites to a sustainable land use system
S2 Reduction in environmental pollution (soil, water, ecosystems, settlements)
S3 Reduction in greenhouse gas (GHG) emissions
S4 Reduction in energy consumption and related costs
S5 Restoration of mining landforms, topography, and landscape
S6 Upgrading of access roads and utilities (water, drainage, electricity, telecom lines)
S7 Development of "green" energy systems (photovoltaics, wind generators, biomass)
S8 Conservation of non-exploited lignite volumes (for strategic purposes)
S9 Construction of new infrastructures/facilities for sustainable businesses
S10 Development of new CE activities in the mining area

Weaknesses—(W)

W1 Low effectiveness of the CSR strategy of the mining company
W2 High capital expenditures (CAPEX) required for the project
W3 Low awareness of CE methods/practices and the concerns of stakeholders/society
W4 Complexity and dysfunctionality of the project
W5 Long project duration and low availability of resources required for project execution
W6 Difficulties in the identification/selection of alternative project strategies
W7 Difficulties in ensuring project financing robustness
W8 Geographical limitations of land use system redesign and repurposing
W9 Poor condition of existing roads, accesses, and soil dumps—AMD effects
W10 Poor coordination between the mining company and permitting authorities

Opportunities—(O)

O1 Enhancement of employment in affected communities
O2 Development (at the local/regional level) of tourism, leisure, and sports
O3 Encouraging agricultural production (arable lands), livestock and reforestation

O4 Encouraging businesses aiming at "green"/renewable energy solutions
O5 Development of low-carbon industry in line with the "3R" principles
O6 Financing R&D for sustainable technological solutions in the extracting industry
O7 Involvement of contractors with reclamation earthworks and construction
O8 Involvement of consulting companies with reclamation engineering/design
O9 Extension of businesses and CE supply chains
O10 Integration of the reclamation/restoration framework with other projects in the region

Threats—(T)

T1 Delays in the issuance of environmental terms and other permits (by authorities)
T2 Failures/delays of contractor work for sustainable mine repurposing
T3 Low participation of interested parties in the stakeholder engagement meetings
T4 Failures/delays in the timeliness of CE method/practice development
T5 Socio-environmental impacts due to the intensive and long-term transformation work
T6 Reaction/reluctance of affected communities regarding mine repurposing/restoration
T7 Financial limitations and/or delays caused by the project lenders and investors
T8 Legislation gaps impeding the transition to sustainability in the extractive industry
T9 Political/social instabilities causing changes in energy policies and development plans
T10 "Force majeure" and project suspension due to global crises, wars, pandemics, etc.
T11 Legal defects related to the mine land's property deeds
T12 HSSE (health, safety, security and environment) events during the reclamation/repurposing/restoration work

5.4. Definition of Strategies

After analyzing the SWOT factors/subfactors, the TOWS/SWOT matrix with the mine-specific sustainability strategies was constructed. The background information for this task was situational analysis, which became the basis for having creative discussions, factual analysis, knowledge exchange, and judgements to prescreen and define several reasonable and feasible strategies. The questions of significant concern, which were thoroughly elaborated, were how and to which extent each strategy can achieve positive results for the society, economy, and environment when the transition project is developed. The inter-disciplinary and cross-disciplinary investigation of all possible scenarios, technical solutions, and sustainability approaches concluded by validating nine (9) alternative strategies. Table 1 provides the TOWS/SWOT matrix structure with the identified strategy descriptions and their taxonomy concerning the influence of SWOT factors.

After WS2 completion, the evaluation team delivered the SWOT factors and the strategic analysis results to their partners and/or professionals with knowledge in sustainability and CE for review. The received feedback was discussed at the opening of WS3, and any reasonable improvements were considered.

Table 1. The TOWS/SWOT matrix.

	Strengths	**Weaknesses**
Opportunities	SO Strategies (maxi-maxi) *"Symbiosis of Lignite Mining, Agriculture, and Biomass"*	WO Strategies (mini-maxi) *"Development of an Agro-Economy"*
	SO1: Operation of lignite mine to fuel thermal power unit(s) that are still in operation and small heat and power cogeneration plants; new CE markets for lignite (e.g., soil amendments and activated carbon) **SO2**: Use of refuse-derived fuels (RDF) produced by local solid waste treatment facilities and development of energy crops on the reclaimed mine areas for the production of biomass that will be burned in small-scale heat and power cogeneration plants **SO3**: Development of greenhouse parks using the heat produced by the power cogeneration plants located nearby	**WO1**: Development of arable land that local farmers will cultivate **WO2**: Development of livestock and beekeeping farming in reclaimed waste heaps that are located close to the mountains that surround the lignite-baring basin
Threats	ST Strategies (maxi-mini) *"The Mines are Transformed into 'Green' Energy Centers"*	WT Strategies (mini-mini) *"Development of Industrial Zones within an Ecologically Restored Area(s)"*
	ST1: Development of photovoltaic parks on horizontal surfaces of waste heaps and expropriated areas that have not been used for the expansion of the mine pits and waste heaps **ST2**: Utilization of the final mine pits as pump reservoirs for both water and energy storage	**WT1**: Development of industrial zones and small-to-medium enterprise (SME) parks in ecologically restored areas that are advantageous due to ease of access, distance from residential areas, the existence of infrastructure and utility networks, availability of recreational facilities, etc. **WT2**: Maximization of surfaces covered by forests and artificial lakes to support the rapid recovery of ecological functions; mild interventions with an emphasis on leisure and sports and other activities improving the quality of life of local people and creating opportunities for the development of tourism

5.5. AHP: Quantification of SWOT Factors

In WS3, the AHP application was conducted for performing pairwise comparisons, constructing reciprocal matrices envisaging the commonly agreed-upon opinions of SMEs, and performing calculations for obtaining the relative weight of SWOT factors and subfactors. The steps which were taken in the AHP application are the following:

(a) Defining the decision-making goal: "Selection of a Project Strategy for Sustainability";
(b) Defining the SWOT factors/subfactor sets: Strengths, S = {S_1, S_2, . . . , S_n; n∈N}; Weaknesses, W = {W_1, W_2, . . . , W_m; m∈N}; Opportunities, O = {O_1, O_2, . . . , Or; r∈N}; Threats, T = {T_1, T_2, . . . , T_s; s∈N};} $1 \leq n \leq 10$; $1 \leq m \leq 10$; $1 \leq r \leq 12$; $1 \leq s \leq 10$; (N: the set of natural numbers);
(c) Structuring the levels of hierarchy:
- Level-1: decision-making goal;
- Level-2: main factors (S, W, O, T);
- Level-3: subfactor sets: S_1, S_2, . . . W_1, W_2, . . . O_1, O_2, . . . T_1, T_2, . . . ;
- Level-4: definition of strategies: STG_1 = SO1, STG_2 = SO2, STG_3 = SO3, STG_4 = WO1, STG_5 = WO2, STG_6 = ST1, STG_7 = ST2, STG_8 = WT1, STG_9 = WT2 (Nos. 9);

(d) Constructing the reciprocal matrix of the main factors, RM_{MF}. Calculation mode: each element a (i, j) of the RM_{MF} matrix corresponds to a reciprocal element a (j, i), where i: row and j: column. The formula for associating these elements is: a (i, j).a (j, i) = 1;
(e) Applying the same calculation mode in the construction of reciprocal matrices for each set of subfactors RM_{SFS}, RM_{SFW}, $RM_{SFO,}$ and RM_{SFT};
(f) Normalizing the data of the RM_{MF} matrix to define the relative weights of the main factors W_S, W_W, W_O and W_T; $0 < W_S, W_W, W_O, W_T < 1$; $W_S + W_W + W_O + W_T = 1$;

(g) Normalizing the data of the RM_{SFS} matrix to define the relative weights W_{S1}, W_{S2}, ..., W_{Sn} of the subfactors $S_1, S_2, \ldots, S_n$; $0 < W_{S1}, W_{S2}, \ldots, W_{Sn} < 1$; $W_{S1} + W_{S2} + \ldots + W_{Sn} = 1$;
(h) Normalizing the data of the RM_{SFW} matrix to define the relative weights W_{W1}, W_{W2}, ..., W_{Wm} of the subfactors $W_1, W_2, \ldots, W_m$; $0 < W_{W1}, W_{W2}, \ldots, W_{Wm} < 1$; $W_{W1} + W_{W2} + \ldots + W_{Wn} = 1$;
(i) Normalizing the data of the RM_{SFO} matrix to define the relative weights W_{O1}, W_{O2}, ..., W_{Or} of the subfactors $O_1, O_2, \ldots, O_r$; $0 < W_{O1}, W_{O2}, \ldots, W_{Or} < 1$; $W_{O1} + W_{O2} + \ldots + W_{Or} = 1$;
(j) Normalizing the data of RM_{SFT} matrix to define the relative weights WT1, WT2, ..., WTs of the subfactors $T_1, T_2, \ldots, T_s$; $0 < W_{T1}, W_{T2}, \ldots, W_{Ts} < 1$; $W_{T1} + W_{T2} + \ldots + W_{Ts} = 1$;
(k) Defining the priority vectors (or eigen vectors) with the relative weights of main factors and subfactors (local values): $PV_{MFi} = [W_S, W_W, W_O, W_T]$; $PV_{SFSi} = [W_{S1}, W_{S2}, \ldots, W_{Sn}]$; $PV_{SFWi} = [W_{W1}, W_{W2}, \ldots, W_{Wmm}]$; $PV_{SFOi} = [W_{O1}, W_{O2}, \ldots, W_{Or}]$; $PV_{SFTi} = [W_{T1}, W_{T2}, \ldots, W_{Ts}]$;
(l) Performing consistency control: the consistency ratio (*CR*) of each matrix must satisfy the condition $CR < 0.1$; otherwise, the pairwise comparisons of the inconsistent reciprocal matrix are reconsidered [7,75–77];
(m) Calculating the global values of the relative weights of the subfactors: $W_{GSi} = [W_{GS1}, W_{GS2}, \ldots, W_{GSn}]$; $W_{GWi} = [W_{GW1}, W_{GW2}, \ldots, W_{GWmm}]$; $W_{GOi} = [W_{GO1}, W_{GO2}, \ldots, W_{GOr}]$; $W_{GTi} = [W_{GT1}, W_{GT2}, \ldots, W_{GTs}]$.

Table 2 shows the scale applied for the pairwise comparisons [73,74]. Table 3 shows the structure of the reciprocal matrix and the outputs of AHP calculations performed for the main factors, while Tables 4–7 present the outputs from the AHP calculations for the S, W, O and T subfactors. In the bottom line of the tables, the results of consistency control are shown.

Table 2. Scale for use in the pairwise comparisons [74].

1	**Equal Importance**
3	Moderate importance of one factor/subfactor to another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance
2, 4, 6	Values of inverse comparison(s)

Table 3. Reciprocal matrix RM_{MF} and priority vector PV_{MFi} of main factors.

Main Factors (MFi)	**S**	**W**	**O**	**T**	$\mathbf{PV_{MFi}}$
S(trengths)	1	1	2	1	$W_s = 0.288$
W(eaknesses)	1	1	2	2	$W_W = 0.338$
O(pporunities)	1/2	1/2	1	1	$W_O = 0.169$
T(hreats)	1	1/2	1	1	$W_T = 0.205$
$n = 4$; $CI = 0.02$; $RI = 0.90$; $CR = 0.022 < 0.10$					1.000

Table 4. Reciprocal matrix RM_{SFS} and priority vector PV_{SFSi} of the subfactor "Strengths".

Strengths, S_i	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	PV_{SFSi}
S_1	1	1	5	3	1/2	3	1	2	2	1	W_{S1} = 0.145
S_2	1	1	4	3	1	2	2	2	2	1	W_{S2} = 0.150
S_3	1/5	1/4	1	1	1/2	2	1	1	1	1	W_{S3} = 0.071
S_4	1/3	1/3	1	1	1/3	1	1	1	1	1	W_{S4} = 0.065
S_5	2	1	2	3	1	3	2	3	3	1	W_{S5} = 0.168
S_6	1/3	1/2	1/2	1	1/3	1	1	3	2	1	W_{S6} = 0.079
S_7	1	1/2	1	1	1/2	1	1	3	3	1/2	W_{S7} = 0.092
S_8	1/2	1/2	1	1	1/3	1/3	1/3	1	1	1/3	W_{S8} = 0.051
S_9	1/2	1/2	1	1	1/3	1/2	1/3	1	1	1/4	W_{S9} = 0.051
S_{10}	1	1	1	1	1	1	2	3	4	1	W_{S10} = 0.128
n = 10; CI = 0.08; RI = 1.49; CR = 0.052 < 0.10											1.000

Table 5. Reciprocal matrix RM_{SFW} and priority vector PV_{SFWi} of the subfactor "Weaknesses".

Weaknesses, W_i	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	PV_{SFWi}
W_1	1	1	1/3	3	1	1	1	2	2	1/2	W_{W1} = 0.094
W_2	1	1	1	3	1/2	2	2	2	3	1	W_{W2} = 0.125
W_3	3	1	1	5	2	3	3	5	3	1	W_{W3} = 0.204
W_4	1/3	1/3	1/5	1	1/2	1/2	1/3	2	3	1/2	W_{W4} = 0.057
W_5	1	2	1/2	2	1	2	2	3	3	2	W_{W5} = 0.145
W_6	1	1/2	1/3	2	1/2	1	1	1	2	1	W_{W6} = 0.076
W_7	1	1/2	1/3	3	1/2	1	1	2	2	1	W_{W7} = 0.086
W_8	1/2	1/2	1/5	1/2	1/3	1	1/2	1	1	2	W_{W8} = 0.062
W_9	1/2	1/3	1/3	1/3	1/3	1/2	1/2	1	1	1/4	W_{W9} = 0.041
W_{10}	2	1	1	2	1/2	1	1	1/2	4	1	W_{W10} = 0.110
n = 10; CI = 0.09; RI = 1.49; CR = 0.058 < 0.10											1.000

Table 6. Reciprocal matrix RM_{SFO} and priority vector PV_{SFOi} of the subfactor "Opportunities".

Opportunities, O_i	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8	O_9	O_{10}	PV_{SFOi}
O_1	1	5	3	2	3	3	5	6	4	2	W_{O1} = 0.254
O_2	1/5	1	1	1	1	1/2	2	2	1	1	W_{O2} = 0.081
O_3	1/3	1	1	1	1	2	2	3	2	1	W_{O3} = 0.104
O_4	1/2	1	1	1	2	3	3	4	3	2	W_{O4} = 0.148
O_5	1/3	1	1	1/2	1	2	2	3	2	1	W_{O5} = 0.097
O_6	1/3	2	1/2	1/3	1/2	1	2	3	2	1	W_{O6} = 0.085
O_7	1/5	1/2	1/2	1/3	1/2	1/2	1	2	1	1/2	W_{O7} = 0.048
O_8	1/6	1/2	1/3	1/4	1/3	1/3	1/2	1	1/2	1/5	W_{O8} = 0.031
O_9	1/4	1	1/2	1/3	1/2	1/2	1	2	1	1/2	W_{O9} = 0.053
O_{10}	1/2	1	1	1/2	1	1	2	5	2	1	W_{10} = 0.100
n = 10; CI = 0.04; RI = 1.49; CR = 0.024 < 0.10											1.000

Table 7. Reciprocal matrix RM_{SFT} and priority vector PV_{SFTi} of the subfactor "Threats".

Threats, T_i	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	PV_{SFTi}
T_1	1	3	2	3	2	2	3	1	1	2	2	2	W_{T1} = 0.140
T_2	1/3	1	1	1	1	1	1	1/2	1/2	1/2	1	1/2	W_{T2} = 0.054
T_3	1/2	1	1	2	1	1/2	1	1	1/2	1	1	1	W_{T3} = 0.063
T_4	1/3	1	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1	1/5	W_{T4} = 0.042
T_5	1/2	1	1	1	1	1	2	1/3	1	2	1/5	2	W_{T5} = 0.075
T_6	1/2	1	2	2	1	1	2	1	1	2	2	1	W_{T6} = 0.091
T_7	1/3	1	1	2	1/2	1/2	1	1	1	1	2	1	W_{T7} = 0.069
T_8	1	2	1	2	3	1	1	1	2	3	3	3	W_{T8} = 0.130
T_9	1	2	2	2	1	1	1	1/2	1	3	1	2	W_{T9} = 0.104
T_{10}	1/2	2	1	2	1/2	1/2	1	1/3	1/3	1	1	1/2	W_{T10} = 0.064
T_{11}	1/2	1	1	1	5	1/2	1/2	1/3	1	1	1	1	W_{T11} = 0.080
T_{12}	1/2	2	1	5	1/2	1	1	1/3	1/2	2	1	1	W_{T12} = 0.089
n = 12; CI = 0.10; RI = 1.48; CR = 0.070 < 0.10													1.000

5.6. Calculations and Ranking

At the closing session of WS3, the evaluation process was completed. First, the performance of the strategies over each subfactor was estimated according to the following escalation mode:

$PS_{i,j}$: Performance of strategy j with respect to the subfactors S_i, $1 \leq i \leq n$ (positive influence)
$PW_{i,j}$: Performance of strategy j with respect to the subfactors W_i, $1 \leq i \leq m$ (negative influence)
$PO_{i,j}$: Performance of strategy j with respect to the subfactors O_i, $1 \leq i \leq r$ (positive influence)
$PT_{i,j}$: Performance of strategy j with respect to the subfactors T_i, $1 \leq i \leq s$ (negative influence)

It is noted that the subfactors S_i and O_i positively influence the performance of the alternatives. Therefore, the higher the influence of these subfactors, the higher the performance value for a specific strategy. Conversely, the subfactors W_i and T_i negatively influence the performance of alternatives. Therefore, the stronger their influence, the lower the performance value. The values used for quantifying strategy performance follow Satay's "intensities for the rating scale" [77], as shown in Table 8.

Table 8. Intensities for the rating scale [77].

Very High	High	Medium	Low	Very Low	Nil
0.42	0.26	0.16	0.10	0.06	0.00

The global relative value of the overall performance for the strategy j, U_j (j = 1, 2, . . . , 9) is calculated by applying the formula below [66]:

$$U_j = \Sigma(W_{GSi})\cdot(PS_{i,j}) + \Sigma(W_{GWi})\cdot(PW_{i,j}) + \Sigma(W_{GOi})\cdot(PO_{i,j}) + \Sigma(W_{GTi})\cdot(PT_{i,j}) \quad (1)$$

$$1 \leq i \leq n \qquad 1 \leq i \leq m \qquad 1 \leq i \leq r \qquad 1 \leq i \leq s$$

For practicality, Equation (1) might be concisely presented as follows:

$$U_j = \Sigma U_{Sj} + \Sigma U_{Wj} + \Sigma U_{Oj} + \Sigma U_{Tj};\ j = 1, 2, \ldots, 9 \quad (2)$$

The calculations and the numerical results of the combined SWOT/AHP method, along with the relative weights (local and global) of all factors and subfactors and their performance on each alternative project strategy, are displayed in Tables S1–S4. Table 9 uses input data from Tables S1–S4, while the calculations for the ranking of strategies are performed using Equation (1). The last line of Table 9 shows the normalized values, U_{Nj}, of the overall performance for each evaluated strategy. Based on the results of Table 9, the ranking of the examined strategies is as follows:

WO1 > WT2 > WO2 > SO1, SO3, ST2 > ST1 > SO2 > WT1

Table 9. Strategy performance results and ranking of alternatives.

	STG_1	**STG_2**	**STG_3**	**STG_4**	**STG_5**	**STG_6**	**STG_7**	**STG_8**	**STG_9**
	SO1	SO2	SO3	WO1	WO2	ST1	ST2	WT1	WT2
ΣU_{Sj}	0.046	0.055	0.052	0.089	0.056	0.061	0.055	0.049	0.060
ΣU_{Wj}	0.066	0.059	0.061	0.088	0.083	0.066	0.072	0.051	0.077
ΣU_{Oj}	0.036	0.034	0.043	0.037	0.028	0.026	0.022	0.032	0.032
ΣU_{Tj}	0.048	0.037	0.040	0.051	0.045	0.041	0.045	0.035	0.047
U_j	0.196	0.185	0.196	0.265	0.212	0.194	0.194	0.167	0.216
U_{Nj}	**0.107**	**0.101**	**0.107**	**0.145**	**0.116**	**0.106**	**0.106**	**0.092**	**0.118**
U_{Nj} (%)	**10.70**	**10.10**	**10.70**	**14.50**	**11.60**	**10.60**	**10.60**	**9.20**	**11.80**

Ranking statistics—Average performance: Av (U_{nj}) = 0.111; Standard deviation: StD (U_{nj}) = 0.015.

From the above, it is assumed that the strategy WO1 is the most preferred for implementing the sustainable transformation project.

6. Discussion

6.1. Methodology Review

The methodology aims to provide solutions, using validated methods and tools, to strategic decision-making problems related to the sustainable transformation of surface lignite mines. The combined SWOT/AHP method enables the development of a participatory framework for the leveraging, balancing, and "digesting" of subjective aspects (judgements of SMEs, knowledge, views, lessons learned, and professional approaches) and objective aspects (situational analysis, restoration and reclamation, post-mining engineering, geoenvironmental investigations, and in situ data collection) which are crucial in the formulation of the strategic concept for sustainable transformation. SWOT is a qualitative method of analysis helpful in identifying factors and subfactors required for evaluating alternative strategies. AHP is a tool that provides mathematical objectivity, validation, and consistency of the calculations performed for the quantification of SWOT factors and subfactors. By applying the combined SWOT/AHP methodology, the decision-making problem can be properly structured and effectively managed [75]. In addition, the SME team allows flexibility, good performance, and time-saving. Therefore, the complexity of the decision-making process can be effectively managed [63].

The contribution of SMEs is important for solving or mitigating other identified problems. For example, the SMEs can provide empirical evidence to answer (a) which principles are adequate for the development of the CE model to ensure value creation from wastes to be reused, recycled, and delivered, and (b) how can new supply chains and markets be formed using raw materials from the post-mining wastes and non-exploited ore. Moreover, the SMEs may provide consultancy in identifying the ecological volume restoration technologies that match the ecological and geoenvironmental characteristics of the mine under research. Furthermore, the knowledge gaps caused by the lack of background and scientific information and the various deficiencies due to unavailability of knowledge and expertise can be faced with the collective work of SMEs or via know-how and technology transfer (KTT) synergies, which can be established before the evaluation process takes place [33]. Additionally, better understanding and familiarization with the legislation and permitting requirements can be sufficiently supported by the SMEs (in workshops). The communication of SWOT analysis results from the SMEs to their partners and/or professionals constitutes a measure to absorb potential misalignments at a later stage. Finally, the pre-screening of engineering solutions required for the transformation and repurposing of the mine, as well as the investigation of the "fit-for-purpose" financing options, can be the result of judgements on technical aspects, budgetary estimations, and consultancy on business and investment management from the members of the SME team specialized in mining operations and project management.

On the other hand, the methodology presents some drawbacks requiring preventive action(s). First, the mobilization of SMEs is not easy and requires early effort and planning, especially when experts are not all available to participate in the evaluation activities at the same time. Second, there are different viewpoints among experts, the members of affected communities, and the permitting authorities, which must be thoroughly analyzed and the most reasonable, practical, and cost-effective ones adapted or synthesized in the context of the SWOT/AHP method application. Third, it is usual for there to be the appearance of disputes among SMEs, stakeholders, or communities [78]. Although creative dialogue is a means of settling these dysfunctions, in certain cases, the workshop coordinators must take the responsibility of resolving such conflicts. Fourth, it is likely that the presentation of evaluation results in public meetings will raise reactions from stakeholders, individuals, or other parties. For this reason, the presentation policy must be very carefully organized and prepared, based on transparency and corporate social responsibility (CSR), including exercises for managing possible questions and answers (Q&As) from the participants, in order for any communication gaps or controversies to be eliminated.

6.2. Interpretation of Results

Table 9 presents the performance value (scores), U_{Nj}, calculated for each alternative strategy. The score of strategy STG_4 = WO1, which refers to the development of *Agro-Economy Activities*, is 14.50% and, as such, the highest. Therefore, WO1 is demonstrated as the most promising strategy. The second best is the strategy STG_9 = WT2, which refers to the *Development of Industrial Zones within an Ecologically Restored area(s)*, with a score of 11.80%. The scores of alternatives are relatively close to each other. For example, the difference between the score of the first-rated strategy WO1 and the score of the last-rated strategy, WT1, is only 5.30%, while the difference between the score of WO1 and the scores of other strategies is much lower. From the ranking statistics shown in the bottom line of Table 9, it is observed that the average performance value Av (U_{nj}) is 11.11%, and the standard deviation StD (U_{nj}) is 0.015, which means that the scores are clustered very closely to the Av (U_{nj}) value. One reason for this "pluralism of opinions" is that, since the number of alternatives is large, there are many options for evaluators (SMEs) to express their preferences.

However, from the performance values of the alternative strategies, it can be pointed out that there is a clear preference for strategies that include mid- and long-term tested (and therefore, low-risk) interventions, such as the development of agricultural businesses and reforestation, compared to interventions that require expertise and development of new infrastructure (e.g., industrial activity zones), interventions that have been tested in the recent past but failed (e.g., energy crops), or interventions that could have been developed for decades but for which there was no willingness consultation with the stakeholders (e.g., greenhouses). In addition, the opinion of the SMEs is not necessarily negative for the interventions that received a low score. It is found that their development is not necessarily linked to the closure of the lignite mines and the need to exploit their reclaimed lands. For example, creating photovoltaic parks is already the first investment activity in the country (or region). It is reasonable and expected that the mine lands would be used for the installation of photovoltaic parks by the mining company. However, there is no need to have any particularly favorable provision for the installation of photovoltaic parks by third parties on mine lands that will be granted to public entities.

Furthermore, in the case of multiple alternatives, each evaluator is very worthy of dealing with the alternative that suits his/her scientific knowledge and disciplinary judgment better. However, the lower the number of alternatives and the higher the differences in performance, the lower is the argumentation on which alternative is the most robust in the consultations with stakeholders and in pre-investment negotiations with the project financing bodies. When the evaluation of post-mining strategies is performed, as an essential part of a well-documented feasibility study to justify the socioenvironmental robustness and techno-economic effectiveness of the alternative options of a post-mine transformation project, the presentation of fewer alternatives is a reasonable policy to avoid time elapses and revisions in the context and content of the feasibility study.

6.3. Improvements in the Selected Strategy

The best strategy ST_4 = WO1 is focused on the encouragement of purely agricultural activities. This perspective is worthwhile with the assumptions that (a) the reclamation and soil improvement work shall recover the soil fertility and nutritious substances to a geochemically appropriate level, and (b) the contaminated underground water shall properly be neutralized, and the effects of AMD shall be reversed entirely. However, the content of the WO1 strategy might be further enriched with multifaceted but costly provisions for the parallel development of livestock and beekeeping, which are mentioned in strategy WO2. Therefore, the two strategies might be synthesized into one. The same can be said for the strategies WT1 and WT2, where the afforestation and ecological restoration can be combined with the regeneration of artificial lakes, the development of low-intensity industrial zones along with tourism and sports activities, which, as a whole, might constitute the basis of merging these strategies into one multi-purposed strategy. In this way, the number of alternatives can be reduced, and the evaluations and decisions can be more solid and quicker, aiming at the introduction of various CE practices/methods for the transition to sustainability, such as industrial ecology, cradle-to-cradle (C2C), closed-loop recycling or other methods [79]. These practices are related to discipline-wise actions and interventions such as biodiversity restoration, hydrogeological improvements, ecoefficiency and eco-effectiveness solutions [5] and improving the air, water and soil quality and wildlife and biodiversity as well [21,35,80].

7. Conclusions and Further Research

This paper proposes a decision-making methodology for evaluating and selecting a sustainable transformation strategy applicable to an ageing, closing, or already closed surface lignite mine. The prototype purpose of the methodology is to show how critical aspects of the evaluation process, namely objectivity, simplicity, knowledge exchange, and transparency, can be effectively managed within a low-cost participatory framework. The methodology is based on expert judgment and knowledge aggregation, with an aim to achieve (a) identification of the factors and subfactors which are critical for strategic decision-making following the TOWS/SWOT method of analysis, and (b) application of the AHP method to perform the hierarchical structuring of the decision-making problem, obtaining the relative weights and calculations required for the ranking and selection of the most advantageous strategy. A team of SMEs with proper qualifications was mobilized and participated in a series of coordinated workshops for exchanging scientific and professional opinions on the strategic aspects of sustainable transformation, discussing conflicting viewpoints, and supporting the execution of calculations and other related work. The methodology might be helpful and implementable by mining operation and project managers, environmentalists, engineers, and, in general, by any entity with authority and/or interest in the transformation of highly impacted mining areas into a productive and properly commercialized land use system of low intensity, with beneficial returns for the society, economy, and environment.

Usually, the decision for the appropriate strategy for sustainability takes place during the elaboration of the feasibility study, when the techno-economic profile and the planning of the transformation project are under preparation. For this reason, the sustainability model should be reasonable, cost-effective, and socio-environmentally friendly, to match mine-specific CE activities and suitable supply chains. In this context, the proposed methodology might be adopted as a practical tool enabling the resolution of problems such as complexity, knowledge gaps, permitting dysfunctions, post-mining engineering considerations, ecological and social aspects, stakeholder management, societal issues, and financial and budgeting issues. The methodology also enables the embodiment of expert knowledge and the utilization of technical data collected during the situational analysis of the mine under research. Furthermore, the interpretation of SME opinions in the form of numerical data increases the objectivity of the methodology, allowing the execution of mathematical calculations with high validity and consistency through the AHP steps. These advantages of the methodology might be used as a strong argument in the presentation of the evaluation outcome during the public consultation work. On the other hand, practical drawbacks of the methodology might be the difficulty in bridging disagreements or conflicts between SMEs and/or other parties, many alternative strategies, a large number of SWOT factors/subfactors, and the potential reactions, justifiable or not, of stakeholders or members of the affected communities during the presentations of the SWOT/AHP methodology results. However, a systematically and adequately prepared, scientifically documented, and well-communicated presentation reduces the risk of reactions, repetitive loops, and revisions of the evaluation results.

The methodology opens windows for further research. One option is for the SWOT analysis to be performed as a qualitative data collection process, open to stakeholders. The list of subfactors and their relative weight could be identified through semi-structured interviews and questionnaires. This way, the participatory part of the SWOT analysis can be performed at the highest possible level. Another option is using fuzzy AHP instead of simple AHP, so that the opinions and preferences of stakeholders and SMEs could be easily expressed using simple linguistic expressions. Beyond, instead of using AHP, other MCDM methods, such as PROMETHEE, DEMATEL, ELECTREE, or other techniques, can be hybridized with the SWOT analysis. Finally, a sensitivity analysis should be adapted to investigate the effects in the ranking results, especially when the values of relative weights presents marginal differences.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15107785/s1, Table S1: Calculation of strategy performance with respect to the strength subfactors; Table S2: Calculation of strategy performance with respect to the weaknesses subfactors; Table S3: Calculation of strategy performance with respect to the opportunities subfactors; Table S4: Calculation of strategy performance with respect to the threats subfactors.

Author Contributions: Conceptualization, P.-M.S. and C.R.; methodology, P.-M.S., C.R. and F.P.; software, P.-M.S., C.R. and F.P.; validation, P.-M.S., C.R. and F.P.; formal analysis, P.-M.S., C.R. and F.P.; investigation, P.-M.S., C.R. and F.P.; resources, P.-M.S., C.R. and F.P.; data curation, P.-M.S., C.R. and F.P.; writing—original draft preparation, P.-M.S.; writing—review and editing, P.-M.S., C.R. and F.P.; visualization, P.-M.S., C.R. and F.P.; supervision, P.-M.S., C.R. and F.P.; project administration, P.-M.S., C.R. and F.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Spanidis, P.-M.; Roumpos, C.; Pavloudakis, F. A Fuzzy-AHP Methodology for Planning the Risk Management of Natural Hazards in Surface Mining Projects. *Sustainability* **2021**, *13*, 2369. [CrossRef]
2. Pavloudakis, F.; Roumpos, C.; Galetakis, M. Public Acceptance of Surface Mining Projects and the Determination of the Marginal Environmental Cost. *Int. J. Min. Reclam. Environ.* **2012**, *26*, 292–308. [CrossRef]
3. Spanidis, P.-M.; Roumpos, C.; Pavloudakis, F. A Methodology Combining IDEF0 and Weighted Risk Factor Analysis for the Strategic Planning of Mine Reclamation. *Minerals* **2022**, *12*, 713. [CrossRef]
4. Environmental Law Alliance Worldwide (ELAW). *Guidebook for Evaluating Project Elias*; Environmental Law Alliance Worldwide (ELAW): Eugene, OR, USA, 2010; ISBN 3978-0-9821214-36.
5. Young, A.; Baretto, M.L. *Towards a Circular Economy Approach to Mining Operations-Key Concepts, Drivers and Opportunities*; Materials Efficiency Research Group (MERG), Environmental Integration Strategies Inc.: Saskatoon, SK, USA, 2021.
6. Brown, L.R. *Building a Sustainable Society*, 1st ed.; A Worldwatch Institute book; Norton: New York, NY, USA, 1981; ISBN 978-0-393-01482-2.
7. World Commission on Environment and Development (WCED). *Our Common Future*; Oxford University Press: Oxford, UK, 1987.
8. Banuri, T.J.; Weyant, G.A.; Akumu, G.; Najam, A.; Pinguelli Rosa, L.; Rayner, S.; Sachs, W.; Sharma, R.; Yohe, G. *Setting the Stage: Climate Change and Sustainable Development*; Climate Change 2001, Mitigation; Intergovernmental Panel on Climate Change (IPCC); Cambridge University Press: Cambridge, UK, 2001.
9. Robinson, J.B.; Herbert, D. Integrating Climate Change and Sustainable Development. *Int. J. Glob. Environ. Issues* **2001**, *1*, 130. [CrossRef]
10. IPCC. *Climate Change 2007: Mitigation of Climate Change: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2007; ISBN 978-0-521-70598-1.
11. Morelli, J. Environmental Sustainability: A Definition for Environmental Professionals. *J. Environ. Sustain.* **2011**, *1*, 2. [CrossRef]

12. Voncken, J.H.L.; Buxton, M.W.N. Sustainability in Mining. In *Chapter 12 of the Book: Critical Minerals-Underlying Causes and Sustainable Mitigation Strategies*; World Scientific: Singapore; Delft University of Technology: Delft, The Netherlands, 2019; pp. 251–263. [CrossRef]
13. Pavloudakis, F.; Roumpos, C.; Spanidis, P.M. Optimization of Surface Mining Operation Based on a Circular Economy Model. In *Circular Economy and Sustainability*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 395–418. ISBN 978-0-12-821664-4.
14. Purvis, B.; Mao, Y.; Robinson, D. Three Pillars of Sustainability: In Search of Conceptual Origins. *Sustain. Sci.* **2019**, *14*, 681–695. [CrossRef]
15. Giddings, B.; Hopwood, B.; O'Brien, G. Environment, Economy and Society: Fitting Them Together into Sustainable Development. *Sustain. Dev.* **2002**, *10*, 187–196. [CrossRef]
16. Buckley, R.C. *Sustainable Development in the Australian Mining and Petroleum Industries: Case Studies and Issues*; Department of Prime Minister and Cabinet: Canberra, Australia, 1990.
17. Buckley, R.C. Sustainability in Mining, Environmental Management and Health. *Environ. Manag. Health* **1992**, *3*, 23–26. [CrossRef]
18. Bradshaw, A. Restoration of Mined Lands—Using Natural Processes. *Ecol. Eng.* **1997**, *8*, 255–269. [CrossRef]
19. Schulz, F.; Wiegleb, G. Development options of natural habitats in a post-mining landscape. *Land Degrad. Dev.* **2000**, *11*, 99–110. [CrossRef]
20. Rovolis, A.; Kalimeris, P. *Roadmap for the Transition of the Western Macedonia Region to a Post-Lignite Era*; WWF Economic and Technical Assessment: Athens, Greece, 2016.
21. McCullogh, C.D. *Key Mine Closure Lessons to Be Learned*; Australian Centre for Geomechanics: Perth, Australia, 2016; pp. 319–332. ISBN 978-0-99248810-4-9.
22. Chuman, T. Restoration Practices Used on Post Mining Sites and Industrial Deposits in the Czech Republic with an Example of Natural Restoration of Granodiorite Quarries and Spoil Heaps. *J. Landsc. Ecol.* **2015**, *8*, 29–46. [CrossRef]
23. Pactwa, K.; Konieczna-Fuławka, M.; Fuławka, K.; Aro, P.; Jaśkiewicz-Proć, I.; Kozłowska-Woszczycka, A. Second Life of Post-Mining Infrastructure in Light of the Circular Economy and Sustainable Development—Recent Advances and Perspectives. *Energies* **2021**, *14*, 7551. [CrossRef]
24. Luminant. *An Overview of Lignite Mine Reforestation at Luminant's Martin Lake Mines in Eastern Texas*; Luminant Co.: Dallas, TX, USA, 2015.
25. Chen, J.; Jiskani, I.M.; Jinliang, C.; Yan, H. Evaluation and Future Framework of Green Mine Construction in China Based on the DPSIR Model. *Sustain. Environ. Res.* **2020**, *30*, 13. [CrossRef]
26. Committee on Technologies for the Mining Industries. *Evolutionary and Revolutionary Technologies for Mining*; National Academies Press: Washington, DC, USA, 2002; p. 102. ISBN 978-0-309-07340-0.
27. Dimitrakopoulos, R. *Orebody Modelling and Strategic Mine Planning*; Springer: Berlin/Heidelberg, Germany, 2018; ISBN 978-3-319-69320-0.
28. Rakhmangulov, A.; Burmistrov, K.; Osintsev, N. Sustainable Open Pit Mining and Technical Systems: Concept, Principles, and Indicators. *Sustainability* **2021**, *13*, 1101. [CrossRef]
29. Aznar-Sánchez, J.A.; Velasco-Muñoz, J.F.; Belmonte-Ureña, L.J.; Manzano-Agugliaro, F. Innovation and Technology for Sustainable Mining Activity: A Worldwide Research Assessment. *J. Clean. Prod.* **2019**, *221*, 38–54. [CrossRef]
30. Mayes, W.M.; Hull, S.L.; Gomes, H.I. From Linear Economy Legacies to Circular Economy Resources: Maximising the Multifaceted Values of Legacy Mineral Wastes. In *Circular Economy and Sustainability*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 409–431. ISBN 978-0-12-819817-9.
31. Vo, T.L.; Nash, W.; Del Galdo, M.; Rezania, M.; Crane, R.; Mousavi Nezhad, M.; Ferrara, L. Coal Mining Wastes Valorization as Raw Geomaterials in Construction: A Review with New Perspectives. *J. Clean. Prod.* **2022**, *336*, 130213. [CrossRef]
32. Saydam, S.; Hebblewhite, B.; Karmis, M.; Hitch, M. *Mines of the Future*; Society of Mining Professors: Morgantown, WV, USA, 2019.
33. Spanidis, P.-M.; Roumpos, C.; Pavloudakis, F.; Servou, A.; Paraskevis, N. Developing Knowledge Management in Mine Reclamation Projects. In Proceedings of the Bulletin of the Geological Society of Greece, Sp. Publ. 10, Patras, Greece, 17 October 2022. Vol. Ext. Abs. GSG2022-338.
34. Sloss, L. Coal Mine Site Reclamation. In *Clean Coal Technology*; IEA: Paris, France, 2013. [CrossRef]
35. Imboden, C.; Moczek, N. *Risks and Opportunities in the Biodiversity Management and Related Stakeholder Involvement of the RWE Hambach Lignite Mine*; International Union for Conservation of Nature and Natural Resources: Gland, Switzerland, 2015.
36. Tischew, S.; Kirmer, A.; Lorenz, A. Alternative Restoration Strategies in Former Lignite Mining Areas of Eastern Germany. In *Biodiversity: Structure and Function*; EOLSS Publishers Co., Ltd.: Oxford, UK, 2009.
37. Fields-Johnson, C.W.; Zipper, C.E.; Burger, J.A.; Evans, D.M. Forest Restoration on Steep Slopes after Coal Surface Mining in Appalachian USA: Soil Grading and Seeding Effects. *For. Ecol. Manag.* **2012**, *270*, 126–134. [CrossRef]
38. McCullough, C.D.; Lund, M.A. Bioremediation of Acidic and Metalliferous Drainage (AMD) through Organic Carbon Amendment by Municipal Sewage and Green Waste. *J. Environ. Manag.* **2011**, *92*, 2419–2426. [CrossRef]
39. Yu, X. Coal Mining and Environmental Development in Southwest China. *Environ. Dev.* **2017**, *21*, 77–86. [CrossRef]
40. Spanidis, P.-M.; Roumpos, C.; Pavloudakis, F. A Multi-Criteria Approach for the Evaluation of Low Risk Restoration Projects in Continuous Surface Lignite Mines. *Energies* **2020**, *13*, 2179. [CrossRef]
41. Araya, N.; Ramírez, Y.; Kraslawski, A.; Cisternas, L.A. Feasibility of Re-Processing Mine Tailings to Obtain Critical Raw Materials Using Real Options Analysis. *J. Environ. Manag.* **2021**, *284*, 112060. [CrossRef] [PubMed]

42. Xu, W.; Wang, J.; Zhang, M.; Li, S. Construction of Landscape Ecological Network Based on Landscape Ecological Risk Assessment in a Large-Scale Opencast Coal Mine Area. *J. Clean. Prod.* **2021**, *286*, 125523. [CrossRef]
43. Kivinen, S. Sustainable Post-Mining Land Use: Are Closed Metal Mines Abandoned or Re-Used Space? *Sustainability* **2017**, *9*, 1705. [CrossRef]
44. Project Management Institute (Ed.) *A Guide to the Project Management Body of Knowledge: PMBOK®Guide*, 5th ed.; PMI Global Standard; PMI: Newtown Square, PA, USA, 2013; ISBN 978-1-935589-67-9.
45. Haney, M.; Shkaratan, M. *Mine Closure and Its Impact on the Community: Five Years after Mine Closure in Romania, Russia and Ukraine*; Policy Research Working Paper; World Bank: Washington, DC, USA, 2003.
46. Swart, E. The South African Legislative Framework for Mine Closure. *J. S. Afr. Inst. Min. Metall.* **2003**, *103*, 469–492.
47. Marais, L.; Atkinson, D. Towards a Post-Mining Economy in a Small Town: Challenges, Obstacles and Lessons From. In Proceedings of the Desert Knowledge Australia, Alice Springs, Australia, 2–4 November 2006.
48. Stacey, J.; Naude, A.; Hermanus, M.; Frankel, P. The Socio-Economic Aspects of Mine Closure and Sustainable Development: Literature Overview and Lessons for the Socio-Economic Aspects of Closure-Report 1. *J. S. Afr. Inst. Min. Metall.* **2010**, *110*, 379–394.
49. Swason, S. What Type of Lake Do We Want? Stakeholder Engagement in Planning for Beneficial End Uses of Pit Lakes. In Proceedings of the Sixth International Conference on Mine Closure, Reno, NV, USA, 2–5 October 2011; Australian Centre for Geomechanics: Crawley, Australia, 2011.
50. Pactwa, K.; Woźniak, J.; Dudek, M. Sustainable Social and Environmental Evaluation of Post-Industrial Facilities in a Closed Loop Perspective in Coal-Mining Areas in Poland. *Sustainability* **2020**, *13*, 167. [CrossRef]
51. Eurostat. *Eurostat Inland Consumption of Brown Coal by EU Member States*; Eurostat: Luxembourg, 2021.
52. Buchholz, P.; Brandenburg, T. Demand, Supply, and Price Trends for Mineral Raw Materials Relevant to the Renewable Energy Transition Wind Energy, Solar Photovoltaic Energy, and Energy Storage. *Chem. Ing. Technol* **2018**, *90*, 141–153. [CrossRef]
53. Stewart, D.G. *Handbook of Western Reclamation of Techniques*, 2nd ed.; University of Wyoming and US Office of Surface Mining Reclamation and Enforcement: Denver, CO, USA, 2006.
54. Yonk, R.M.; Smith, J.T.; Wardle, A.R. Exploring the Policy Implications of the Surface Mining Control and Reclamation Act. *Resources* **2019**, *8*, 25. [CrossRef]
55. Pavloudakis, F.; Roumpos, C.; Karlopoulos, E.; Koukouzas, N. Sustainable Rehabilitation of Surface Coal Mining Areas: The Case of Greek Lignite Mines. *Energies* **2020**, *13*, 3995. [CrossRef]
56. Feting, C. *The European Green Deal*; ENDS Office: Vienna, Austria, 2020.
57. Smol, M.; Marcinek, P.; Duda, J.; Szołdrowska, D. Importance of Sustainable Mineral Resource Management in Implementing the Circular Economy (CE) Model and the European Green Deal Strategy. *Resources* **2020**, *9*, 55. [CrossRef]
58. Bellini, G.A.; Mathieu, F.; Mancini, L.; Nyberg, M.; Viejas, H.M. *JERK Science for Policy Report. Recovery of Critical Raw and Other Materials from Mining Waste and Landfills–State of Play on Existing Practices*; European Commission: Brussels, Belgium, 2019.
59. Szwed, P.S. *Expert Judgment in Project Management: Narrowing the Theory-Practice Gap*; Project Management Institute Inc: Newtown Square, PA, USA, 2016; ISBN 978-1-62825-146-3.
60. Hopkins, P.; Unger, M. What Is a "Subject-Matter Expert"? *J. Pipeline Eng.* **2017**, *16*, 227–230.
61. Chang, H.-H.; Huang, W.-C. Application of a Quantification SWOT Analytical Method. *Math. Comput. Model.* **2006**, *43*, 158–169. [CrossRef]
62. Kangas, J.; Kurttila, M.; Kajanus, M.; Kangas, A. Evaluating the Management Strategies of a Forestland Estate—The S-O-S Approach. *J. Environ. Manag.* **2003**, *69*, 349–358. [CrossRef] [PubMed]
63. Ghazinoory, S.; Abdi, M.; Azadegan-Mehr, M. SWOT Methodology: A State-of-the-Art Review for the Past, A Framework for the Future. *J. Bus. Econ. Manag.* **2011**, *12*, 24–48. [CrossRef]
64. Weihrich, H. The TOWS Matrix—A Tool for Situational Analysis. *Long Range Plann.* **1982**, *15*, 54–66. [CrossRef]
65. Hill, T.; Westbrook, R. SWOT Analysis: It's Time for a Product Recall. *Long Range Plann.* **1997**, *30*, 46–52. [CrossRef]
66. Wickramasinghe, V.; Takano, S. Application of Combined SWOT and Analytic Hierarchy Process (AHP) for Tourism Revival Strategic Marketing Planning: A Case of Sri Lanka Tourism. *J. East Asia Soc. Transp. Stud.* **2010**, *8*, 954–969.
67. Kangas, J.; Pesonen, M.; Kurtila, M.; Kajanus, M. A'WOT: Integrating AHP with SWOT Analysis. In Proceedings of the 6th International Symposium on the Analytic Hierarchy Process (ISHAP), Bern, Switzerland, 2–4 August 2001; pp. 189–198.
68. Ishizaka, A.; Labib, A. Review of the Main Developments in the Analytic Hierarchy Process. *Expert Syst. Appl.* **2011**, *38*, 14336–14345. [CrossRef]
69. Dey, P.K. A Risk-based Model for Inspection and Maintenance of Cross-country Petroleum Pipeline. *J. Qual. Maint. Eng.* **2001**, *7*, 25–43. [CrossRef]
70. Kraujalienė, L. Comparative Analysis of Multicriteria Decision-Making Methods. Evaluating the Efficiency of Technology Transfer. *Bus. Manag. Educ.* **2019**, *17*, 72–93. [CrossRef]
71. Triantaphyllou, E. *Multi-Criteria Decision Making Methods: A Comparative Study*; Applied Optimization; Springer US: Boston, MA, USA, 2000; Volume 44, ISBN 978-1-4419-4838-0.
72. Velasquez, M.; Hester, P.T. An Analysis of Multi-Criteria Decision Making Methods. *Int. J. Oper.* **2013**, *10*, 56–66.
73. Saaty, T.L. *The Analytic Hierarchy Process*; RWS Publications: Pittsburgh, PA, USA, 1980.
74. Saaty, T.L.; Vargas, L.G. *Prediction, Projection and Forecasting*; Springer: Dordrecht, The Netherlands, 1991; ISBN 978-94-015-7954-4.

75. Al-Harbi, K.M.A.-S. Application of the AHP in Project Management. *Int. J. Proj. Manag.* **2001**, *19*, 19–27. [CrossRef]
76. Saaty, T.L. Decision Making with the Analytic Hierarchy Process. *Int. J. Serv. Sci.* **2008**, *1*, 83–98. [CrossRef]
77. Saaty, T. *Decision Making with Dependence and Feedback: The Analytic Network Process: The Organization and Prioritization of Complexity*; RWS Publications: Pittsburgh, PA, USA, 1996.
78. Padur, K.; Purre, A.-H. Optimizing Post-Mining Land-Use Decision Making in Cooperation with Stakeholders. *Environ. Dev. Sustain.* **2022**, *24*, 4875–4900. [CrossRef]
79. Bacovis, M.M.C.; Nascimento-e-Silva, D.; Borchardt, M.; de Melo, A. Framework Proposal to Organize Sustainability Strategies Towards a Transition to the Circular Economy. In *Industrial Engineering and Operations Management*; Thomé, A.M.T., Barbastefano, R.G., Scavarda, L.F., dos Reis, J.C.G., Amorim, M.P.C., Eds.; Springer Proceedings in Mathematics & Statistics; Springer International Publishing: Berlin/Heidelberg, Germany, 2020; Volume 337, pp. 257–272. ISBN 978-3-030-56919-8.
80. Geisendorf, S.; Pietrulla, F. The Circular Economy and Circular Economic Concepts-a Literature Analysis and Redefinition. *Thunderbird Int. Bus. Rev.* **2018**, *60*, 771–782. [CrossRef]