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REPURPOSING POST-MINING AREAS IN THE ENERGY TRANSITION OF REPUBLIKA SRPSKA: CHALLENGES AND OPPORTUNITIES

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Abstract

The subject of this paper is the energy transition process in Republika Srpska, with a primary focus on the strategic repurposing of post-mining areas into solar power plants. The research examines the transformation of degraded technogenic land into potential energy capacities, contributing to decarbonization and the revaluation of previously degraded areas. The aim of the study is to assess the technical feasibility, environmental justification, and socio-economic implications of installing solar systems on sites where mining activities have ceased. The theoretical framework integrates concepts such as EROEI and green innovation, while a quantification model applied to the Stanari case study illustrates long-term potential. Empirical research conducted on a sample of 180 respondents indicates a high level of social acceptance (83%) for the solarization of open-cast mines. The results suggest that repurposing post-mining land may contribute to mitigating economic stagnation and improving energy security through the modernization of technogenic landscapes.

Keywords: *energy transition, solar energy, Republika Srpska, decarbonization, technogenic soil.*

1 INTRODUCTION

The global goal of climate neutrality by 2050 requires a gradual transition from fossil fuels to renewable energy systems [1]. In coal-dependent economies such as Republika Srpska (Bosnia and Herzegovina), this process creates significant socio-economic and structural challenges. The regional energy sector relies on thermal power plants (TPPs) in Stanari, Gacko, and Ugljevik, which ensure energy stability but also cause environmental degradation and technogenic soil disturbance [2]. Therefore, the repurposing of post-mining land for utility-scale solar photovoltaic (PV) systems represents an important pathway for a just energy transition. Land reclamation in mining areas has traditionally focused on agricultural and forestry restoration, often producing low-fertility deposols with limited economic value [3]. Recent energy policies increasingly recognize brownfield mining sites as suitable locations for large-scale solar projects because they use existing grid infrastructure and reduce pressure on undeveloped land [4]. However, the deployment of PV systems on technogenic soil depends on terrain stability,

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soil consolidation, workforce adaptation, and public institutional support [5]. This paper evaluates the technical feasibility, environmental justification, and socio-economic aspects of solar energy development on post-mining land in Republika Srpska, using the Mine-TPP Stanari system as a case study. The research applies the Energy Transition Index (Iet) and empirical survey data from N = 180 respondents to assess public acceptance and generational perspectives regarding the energy transition. The results indicate that combining land reclamation with renewable energy development may support sustainable regional growth and improve the utilization of degraded mining areas.

2 THERMAL POWER SECTOR IN REPUBLIKA SRPSKA

2.1 Generation Structure and Coal Dependency

The electricity sector is an important economic driver in Bosnia and Herzegovina, relying on domestic natural resources to support energy stability and regional electricity exports [1], [2]. In Republika Srpska, electricity generation is predominantly based on lignite and brown coal [3]. Most extracted coal is used in thermal power plants (TPPs), while smaller quantities are supplied to industry and district heating systems. The main production centers are TPP Gacko, TPP Ugljevik, and TPP Stanari, connected to the Gacko, Ugljevik, and Stanari coal basins.

Table 1. *Coal Reserves Balance in the Republika Srpska*

No.	Mine (type)	Balance reserves (000 t)	Potential reserves (000 t)	Exploitable reserves (000 t)	Hd (GJ/t)	Ash (%)	Sulfur (%)
1	Ugljevik (B)	247,409	114,558	206,507	13.28	19.4	4.59
2	Stanari (L)	82,559	9,596	73,271	9.65	5.74	0.17
3	Gacko (L)	269,958	-	245,662	10.28	15.78	1.48
4	Miljevina (B)	21,200	40,100	19,080	11.7-14.8	24.83	2.2
5	*Kotor Varoš*(B)	16,410	1,359	-	14.5	26.06	1.4
6	*Lješljani* (B)	8,843	10,000	-	14.39	28.04	1.53
7	*Ramići* (L)	37,596	37,596	33,836	9.68	15.82	3.88
Total	-	**683,975**	**175,613**	**578,356**	-	-	-

Source: *ERS, Thermo-energetic potential (Accessed: March 2026)*

Although significant reserves exist in Kotor Varoš, Ramići, and Lješljani, their exploitation is currently not planned due to high transport costs and distance from existing processing facilities.

Figure 1 *Spatial distribution of coal deposits and thermal power plants in Republika Srpska*
Source: *Adapted from ERS and Znanje.org.*

2.2 Environmental Impact of the Thermal Power Sector

Thermal power plants generate significant environmental impacts through gaseous emissions, particulate matter, and solid waste streams [4]. Due to the dominant use of coal, thermal power generation remains one of the largest sources of sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions in Bosnia and Herzegovina [5]. In addition to combustion-related pollution, open-cast coal mining causes extensive land degradation. Excavation alters geological structures, haulage activities generate dust and vibrations, while waste rock dumping creates permanent technogenic landforms. Research shows that replacing diesel haulage with conveyor transport systems and relocating crushing facilities closer to mining fronts can improve energy efficiency and reduce dust, noise, and greenhouse gas emissions [6], [7]. Mining activities and waste disposal sites also reduce the availability of agricultural and forest land [8]. Fly ash, slag, and industrial waste heat additionally contribute to soil and groundwater degradation [9], [10]. To reduce the risk of heavy metal contamination, waste disposal sites must be constructed on stable, low-permeability surfaces with adequate drainage systems [11]. Effective mitigation of these impacts requires continuous institutional supervision and environmental regulation [12]. Environmental performance can be evaluated using the Overall Performance Trend (OPT) index:

$$OPT_t = \frac{1}{n}\sum_{i=1}^{n} \frac{X_{ref,i} - X_{t,i}}{X_{ref,i}}$$

Where OPT_t represents the overall performance trend in year *t*, $X_{ref,i}$ is the baseline value of indicator i in the reference year, $X_{t,i}$ is the measured value in the observed year, and *n* denotes the total number of monitored indicators. Positive index outcomes signal progressive environmental restoration, whereas negative trends confirm ecological regression and operational inefficiencies.

3 MANAGEMENT OF POST-MINING AREAS AS AN ECOLOGICAL TRANSITION ELEMENT

3.1 Management Models and Reclamation Concepts in Republika Srpska

Land reclamation is necessary to reduce mining impacts and restore degraded areas to functional use [13]. In Republika Srpska, reclamation activities are primarily defined by legal obligations and mine development plans and may be conducted during or after mining operations [14]. The basic reclamation cost per unit area (Tr) is calculated as [15]:

$$T_r = \frac{C_t + C_b}{S_v}$$

Where C_t and C_b represent technical and biological reclamation costs, while S_v denotes the reclaimed area. More advanced assessments also include geological degradation factors and socio-economic parameters [16], [17]:

$$E_p = A \cdot t_p \cdot T_r$$

Where *A* is annual production and t_p the duration of land occupation. The overall effect of restoring natural potential is expressed as:

$$E = \sum_{i=1}^{n} (P_r - P_p)\,(C_i - C_{vi})\,S_{vi} \cdot t_{vi}$$

Where P_r and P_p represent productivity before and after reclamation, C_i and C_{vi} denote unit prices and variable costs, S_{vi} is the reclaimed surface area, and tvi is the duration of land use. Mechanical stabilization of technogenic soil is a prerequisite for the installation of photovoltaic (PV) systems. Historically, only 15–20% of degraded land in Bosnia and Herzegovina has been reclaimed, while reclamation levels in the Gacko, Ugljevik, and Stanari basins remained around 10% during the 2009–2010 period [15], [18]. Traditional reclamation methods mainly included afforestation and grassland development, whereas recent studies emphasize the potential of technogenic land for bioenergy and solar infrastructure [13], [19]. Projects such as TPP Gacko II include integrated technical and biological reclamation measures [20], although implementation is often limited by financial and technical constraints. At the Ugljevik Istok 1 mine, overburden is deposited in 10 m benches with a planned capacity of 116 million m^3 [21]. Long-term slope stability remains essential for the safe installation of PV systems, with recommended gradients generally ranging from 1:4 to 1:2 under controlled conditions [22].

3.2 Energy Transition Quantification Model: The Case of TPP Stanari

To operationalize the structural shift from fossil fuels to renewable energy, this study applies the Energy Transition Success Index (I_{et}) to systematically evaluate the macro-potential of the Stanari mining basin [23]:

$$I_{et} = \frac{P_{sol}}{P_{ug} \cdot IQI}$$

Where I_{et} represents the Energy Transition Success Index for a specific Mine-TPP system, P_{sol} is the assumed capacity of solar power plants on reclaimed areas (MW), P_{ug} denotes the existing capacity of the coal-fired thermal power plant (MW), and *IQI* is the Institutional Quality Index (ranging from 0.1 to 1.0). To prevent an unrealistic inflation of the transition index, uncertainty weighting was applied to the *IQI* coefficient, assigning lower weights to operational variables that lack comprehensive legal regulation. The EFT Mine and TPP Stanari system serves as a highly representative case study due to its advanced technological efficiency and infrastructural setup. Based on strategic projections, the baseline scenario involves an initial 5 MW solar installation on technogenic land acting as an innovation seed impulse [24], with a strategic scaling target of 300 MW by 2040. Spatial planning relies on available asset polygons within the Stanari basin: the northern Raškovac open-pit mine encompasses 1,123 ha [25], while the southern Ostružnja open-pit mine covers 893 ha [26], encompassing mining fields, overburden dumps, and utility corridors. The simulation targets a full structural substitution by 2040, where the baseline thermal capacity (P_{ug} = 300 MW) is systematically matched by planned solar capacity (P_{sol} = 300 MW), as detailed in Table 2.

Table 2 *Simulation of the Energy Transition Index (Iet) based on the projected scenario*

Transition Phase	Solar Capacity (P_{sol})	Coal Capacity (P_{ug})	Assumed *IQI*	Results (I_{et})
Phase I (2025)	5 MW	300 MW	0.9	0.018
Projected Goal (2040)	300 MW	300 MW	0.9	1.11

The simulation demonstrates that by 2040, the index exceeds unity (I_{et} > 1), indicating a successful structural transition [23]. Crucially, this macro-scenario aligns with a high baseline of social readiness and ensures long-term employment stability for up to 1,250 workers. Clarification on Workforce Feasibility: The capacity of 1,250 employees does not represent the direct operational crew required for PV panel maintenance, which is inherently low. Instead, this figure reflects the total workforce retention capability of the integrated Mine-TPP Stanari complex during its phased transition. Maintaining this employment level is technically and economically feasible because the gradual decommissioning of coal generation triggers a labor reallocation toward extensive, long-term post-mining activities. These include complex technical and biological land reclamation, continuous environmental monitoring, mine closure conservation, grid infrastructure modernization, and the management of regional circular economy initiatives. Within the framework of the internal-influence growth pattern [24], this holistic absorption model prevents regional socio-economic stagnation by treating the legacy workforce as an internal institutional asset. Consequently, instead of relying on external labor markets, the system dynamically reallocates its existing human capital to drive localized ecological and infrastructural value creation throughout the decommissioning lifecycle [24].

3.3 Comparative Analysis of European Practices in Mining Area Repurposing

European examples confirm the feasibility of converting post-mining land into utility-scale solar facilities using existing grid infrastructure. One example is the Klettwitz lignite mine in Germany, which was transformed into a 170 MW photovoltaic plant [27]. Within the framework of the European Green Deal, such projects combine land reclamation with renewable energy development to support climate neutrality goals [28], [29]. Successful transition models generally rely on gradual implementation. In the Horná Nitra region of Slovakia, phased mine closure combined with renewable energy projects contributed to regional economic stability [30]. In contrast, rapid coal phase-out without compensatory development may lead to demographic and employment decline, as projected in parts of Polish Silesia [31], [32]. For Republika Srpska and the Western Balkans, the Green Agenda for the Western Balkans emphasizes decarbonization, ecological restoration, and a just transition framework [33]. In this context, the repurposing of degraded mining land into solar energy facilities represents a practical approach for supporting both environmental goals and long-term energy security.

4 DEVELOPMENT POTENTIAL OF SOLAR ENERGY ON TECHNOGENIC MINING LAND

4.1. Technical and Environmental Potential

Reclaimed mining land represents a suitable location for utility-scale solar energy development because it combines land restoration with low-emission energy production. Unlike conventional thermal power plants, photovoltaic (PV) systems do not produce carbon dioxide (CO_2) or particulate emissions during operation [34]. Their installation on degraded mining areas enables the use of existing brownfield sites without additional occupation of agricultural or undeveloped land. Solar energy also provides reliable electricity generation, local economic benefits, and increased public environmental awareness [35]. In Republika Srpska, post-mining landscapes therefore represent significant potential for renewable energy deployment. However, successful implementation requires the stabilization of technogenic soils together with ecological restoration through forestry, bioenergy, or controlled agricultural use.

4.2 Socio-economic Aspects and Constraints of the Energy Transition

The energy transition in coal-dependent regions has significant socio-economic implications. Energy costs account for 15–40% of mining operating expenses, making the sector highly sensitive to market changes and energy price fluctuations [36]. Research shows that reducing fossil fuel dependence and increasing renewable energy use may contribute to lower carbon emissions and improved long-term economic stability [37]. One of the key indicators used to evaluate alternative energy systems is the Energy Return on Energy Invested (EROEI) [38]:

$$EROEI = \frac{E_{output}}{E_{input}}$$

Where E_{output} represents the total energy produced, while E_{input} denotes the energy required for construction and maintenance. Fossil fuels traditionally achieved high EROEI values, while early photovoltaic systems showed lower efficiency ratios. To accelerate the energy transition, financial support for research, development, and grid modernization remains necessary [39]. The economic competitiveness of renewable energy systems is additionally defined by the backstop technology condition [40]:

$$p_t \leq R$$

Where p_t represents the unit price of renewable energy and R denotes the operational cost threshold of conventional technologies. As the costs of photovoltaic systems and energy storage continue to decline, solar energy is becoming increasingly competitive in Republika Srpska. Combined with strong public support (83%), this indicates that the repurposing of degraded mining land into solar energy facilities may support employment preservation and long-term energy security.

5 ANALYSIS OF EMPIRICAL RESULTS

5.1 Materials and Methods

An empirical survey was conducted between February and March 2026 to examine public perceptions regarding the conversion of post-mining land into solar energy facilities in Republika Srpska. Data were collected through a structured questionnaire distributed in digital and printed form across mining-dependent municipalities. The survey ensured respondent anonymity and confidentiality. Of 183 contacted individuals, 180 completed the questionnaire, resulting in a final sample of N = 180 and a response rate of 98.3%.

5.2 Socio-demographic and Geographical Profile of the Sample

The sample consisted of 63.0% male and 37.0% female respondents. The largest age groups were 26–35 years (25.0%) and 36–45 years (24.0%), followed by respondents aged 46–55 years (20.0%). These groups represent the core working population directly connected to the mining and thermal power sector. Respondents originated primarily from energy- and mining-dependent municipalities. The largest shares came from Doboj (27.8%) and Stanari (15.0%), while Gacko, Ugljevik, and Bijeljina each accounted for 8.3% of the sample.

5.3 Public Perception of Technological, Economic, and Environmental Drivers

Respondent attitudes were analyzed through three focused operational indicators: support for solar installations on post-mining land (P1), regional employment expectations (P2), and environmental concerns related to biodiversity protection (P3) [41].

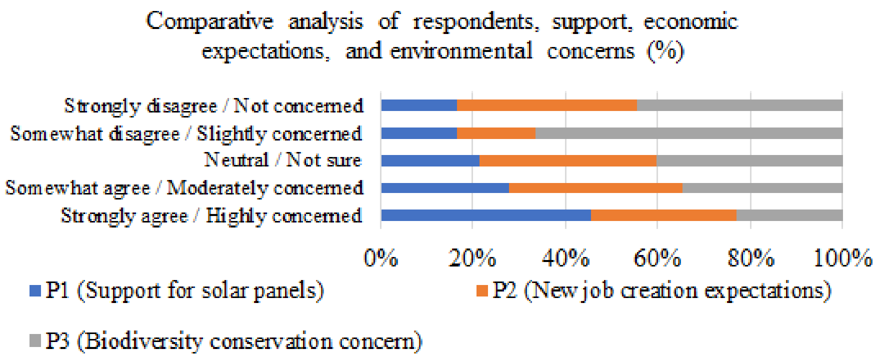

Figure 2 *Comparative analysis of respondents' attitudes toward solar park installation (%)*

Source: *Author's own research (2026).*

The empirical results presented in Figure 2 indicate the following key findings:

- P1 (Support for installation): A cumulative 62.0% of respondents express explicit support for the construction of solar parks on post-mining land, combining those who strongly agree at 46.0% and somewhat agree at 16.0%. This strong consensus indicates a highly positive public attitude towardbrownfield renewable energy development.
- P2 (Employment expectations): Socio-economic expectations remain more moderate, with 54.0% of respondents believing that solar projects will contribute to regional employment (comprising 31.0% who strongly agree and 23.0% who somewhat agree). This points to a measured, cautious stance when comparing renewable integration with traditional, highly stable mining employment.

- P3 (Environmental concern): Local ecosystem integrity remains an active public focus, with 23.0% of respondents expressing high levels of apprehension regarding potential biodiversity loss and the reduction of active green areas, emphasizing the necessity of embedding strict ecological mitigation measures into early project planning.

5.4 Cross-Sectional Generational Analysis (Age Groups 26–35 and 36–45)

A separate analysis was conducted for the two dominant workforce groups: respondents aged 26–35 years (n = 45) and 36–45 years (n = 43).

- P1 (Support for installation): Support for solar projects was higher among respondents aged 26–35 years (71.1%) compared to the 36–45 group (58.1%).
- P2 (Employment expectations): The 36–45 cohort expressed lower confidence regarding employment opportunities from solar projects (41.9%) compared to respondents aged 26–35 years (60.0%).
- P3 (Environmental concern): Environmental concerns were more pronounced among younger respondents aged 26–35 years (28.9%) than in the 36–45 group (18.6%).

The results indicate that younger respondents show stronger support for renewable energy projects, while middle-career workers express greater concern regarding long-term employment stability.

5.5 Social Responsibility and Generational Consensus

Additional indicators evaluated perceptions of community support, industrial infrastructure utilization, and public well-being (Figure 3).

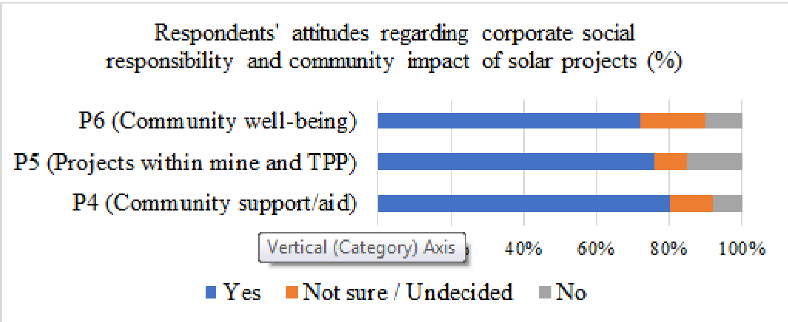

Figure 3 *Respondents' perception of community support and social benefits (%)*
Source: *Author's own research (2026).*

The results show:

- P4 (Community support): 80.0% of respondents support structured assistance programs for mining-dependent communities during the energy transition process.
- P5 (Projects within mining and TPP systems): 76.0% support implementing solar projects within existing mining and thermal power infrastructure systems.
- P6 (Community well-being): 72.0% consider solar energy projects

beneficial for long-term community development and environmental improvement.

Overall, the empirical findings indicate broad public support for renewable energy development on post-mining land in Republika Srpska. However, respondents also emphasize the importance of employment protection, environmental reclamation, and institutional support measures during the transition process.

6 CONCLUSION

This research confirms that the energy transition in Republika Srpska can be progressively achieved through the phased technical reclamation of post-mining landscapes and their functional conversion into utility-scale solar clusters. The quantification model applied to the Mine-TPP Stanari complex demonstrates that scaling solar capacity to 300 MW by 2040 drives the Energy Transition Index above unity ($I_{et} > 1$). This macro-level trajectory enables a non-disruptive phase-out of legacy coal generation while systematically safeguarding regional grid and energy stability. These structural projections are firmly validated by the cross-sectional empirical findings, which document a high baseline of social readiness and institutional trust regarding brownfield infrastructure substitution. The empirical insights reveal that successful deployment cannot rely solely on technical installation; rather, it demands a hybrid planning model that seamlessly binds technological substitution with intensive post-mining biological reclamation and socio-economic workforce reallocation frameworks. This approach bridges the structural perception gap between localized employment security expectations (P2) and underlying anxieties regarding ecosystem integrity (P3), a dynamic most pronounced within the critical 26–35 and 36–45 workforce cohorts. Furthermore, strategic social safe guarding represents a fundamental condition for long-term project viability, as evidenced by the overwhelming public mandate for binding institutional and financial assistance for affected communities (P4). This requirement directly aligns with the foundational pillars of the Green Agenda for the Western Balkans, illustrating that regional decarbonization must secure alternative livelihood mechanisms to prevent structural stagnation.

Future research should focus on further differentiating empirical responses between active mining jurisdictions and non-extractive municipalities to eliminate aggregation bias and strengthen the spatial robustness of socio-economic impact assessments. In conclusion, integrating advanced technogenic land reclamation with brownfield renewable energy development represents a highly efficient model for transforming disrupted industrial basins into active drivers of sustainable regional growth. This integrated approach serves as a vital strategic pathway for strengthening long-term energy security, technological modernization, and economic resilience in Republika Srpska.

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