



MULTI-CRITERIA TOOL FOR ASSESSING THE SOCIAL ACCEPTANCE OF RM-GES GRAVITY ENERGY STORAGE PROJECTS IN POST-MINING SITES

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DOI: 10.2478/minrv-2026-0053

received – 03.08.2026 / revised – 17.08.2026

accepted – 10.09.2026 / published – 25.09.2026

Abstract: The deployment of Rail-based Mine Gravity Energy Storage (RM-GES) technology in post-mining regions requires a systematic assessment of social acceptance conditions as a prerequisite for investment and regulatory approval. This paper presents the development, internal validation, and pilot empirical application of a standardised Multi-Criteria Analysis (MCA) framework for assessing the social acceptance of RM-GES, developed within the GrEnMine project (Research Fund for Coal and Steel, RFCS-2023-01-RPJ). The framework examines social acceptance across six dimensions-socio-political acceptance, community acceptance, market acceptance, risk perception, institutional trust, and perceived equity-aligned with Regulation (EU) 2021/1056 establishing the Just Transition Fund (JTF). Six standardised instruments were developed and validated for multilingual administration across the four GrEnMine pilot regions; the present pilot applied the Romanian-language versions only. Pilot data from the Petrila Living Lab (Jiu Valley, Romania), comprising 112 questionnaire responses, four interviews with public authority representatives, two focus groups ($n = 23$ participants), and 98 equity questionnaires, yielded a preliminary composite MCA score of 66/100, classified as „recommended with conditions”. A sensitivity analysis conducted across six weighting scenarios demonstrated score stability (± 4 points). The main finding is that 68% of focus-group participants expressed conditional rather than unconditional acceptance, with the coexistence of RM-GES infrastructure and industrial heritage emerging as the primary condition for acceptance. This finding is directly relevant to RM-GES project design in the context of the Jiu Valley.

Keywords: RM-GES; gravity energy storage; social acceptance; post-mining communities; Just Transition; Jiu Valley.

1. Introduction

The closure of coal mines across Central and Eastern Europe under the European Green Deal and the energy transition supported by Just Transition Fund (JTF) presents both a challenge and an opportunity for post-mining regions. The socio-economic challenge involves large-scale unemployment, a decline in the regional tax base, and the deterioration of infrastructure dependent on active mining operations. The technological opportunity lies in repurposing the physical infrastructure of closed mines-including galleries, rail transport systems, and electrical substations-for new productive uses without incurring the capital costs associated with developing entirely new facilities [1].

Rail-based Mine Gravity Energy Storage (RM-GES) represents one such repurposing opportunity. By using existing inclined mine galleries to raise and lower heavy rail vehicles, RM-GES stores electrical energy in the form of gravitational potential energy and provides grid-balancing services without relying on critical raw materials such as lithium and cobalt or requiring additional land take [2, 3]. Romania's Jiu Valley region-home to five historically significant underground coal mines, all either closed or undergoing transition, and covered by the Hunedoara Territorial Just Transition Plan-is among the European regions with the most promising technical potential for RM-GES deployment [4].

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However, the extensive literature on energy technology deployment consistently demonstrates that technical feasibility and economic viability are necessary but insufficient conditions for successful implementation. Social acceptance-the extent to which communities, institutions, and market actors support or tolerate a technology-influences deployment timelines, permitting outcomes, and long-term operational stability [5, 6]. In post-mining communities, social acceptance is specifically shaped by historically accumulated institutional distrust, strong occupational identities, and the distinctive dynamics of industrial heritage [7, 8].

This paper presents the MCA framework for assessing social acceptance developed under GrEnMine project[†] (RFCS-2023-01-RPJ), with a pilot application focused on the Jiu Valley. The results presented in this paper constitute the first pilot application of the proposed framework within the GrEnMine project. In the subsequent stages of the project, the same standardised research methodology will be implemented in three additional pilot regions located in Poland, Greece, and the Czech Republic. The comparative analysis of social acceptance across the four post-mining regions will enable the identification of common and region-specific determinants influencing the acceptance of RM-GES technology and will provide the basis for validating the applicability and robustness of the proposed MCA framework under different socio-economic, cultural, and institutional conditions. Ultimately, this cross-country comparison is expected to support the development of evidence-based recommendations for socially acceptable deployment of RM-GES technologies across European coal transition regions.

The remainder of the paper is structured as follows: Section 2 presents the theoretical background; Section 3 describes the MCA framework and research instruments; Section 4 reports the pilot results obtained at the Petrila Living Lab; Section 5 discusses the findings; and Section 6 presents the conclusions.

2. Theoretical background

The social acceptance of energy technologies was theoretically conceptualised by Wüstenhagen et al. [5] as a tripartite construct comprising socio-political acceptance (at the national/regional policy and institutional level), community acceptance (among local residents living near the installations), and market acceptance (among investors and energy market actors). This model has been extensively validated in the wind energy literature [9] and applied, with adaptations, to energy storage technologies [10].

In post-mining contexts, two additional dynamics extending beyond the tripartite model require specific analytical attention. First, the risk perception dimension is systematically more pronounced than in energy projects developed on greenfield sites: communities with direct experience of underground operations possess detailed, historically informed mental models of underground risks that do not correspond directly to RM-GES risk profiles [7, 11]. Second, industrial heritage functions as a mediating variable in acceptance decisions: communities that have invested in heritage recognition are more likely to accept technological transformation when the project design explicitly accommodates coexistence with industrial heritage [12].

Multi-Criteria Analysis (MCA) provides a transparent framework for integrating heterogeneous dimensions of acceptance into a composite indicator [13]. In the specific context of the JTF, MCA enables the simultaneous assessment of social acceptance and eligibility for JTF co-financing, as the six dimensions correspond directly to specific provisions of Regulation (EU) 2021/1056 (Table 1). This approach transforms social acceptance research from a risk-management exercise into a mechanism for identifying value for investors [14].

3. The MCA framework and research instruments

3.1 Framework Architecture

The MCA framework assesses social acceptance across six dimensions (Table 1), each operationalised through one or more standardised research instruments and mapped to a specific provision of the JTF regulatory framework. The dimension weights were established through a two-round Delphi procedure involving 14 experts from the four GrEnMine partner countries. The resulting weights were informed by both the social acceptance literature and expert consensus on acceptance dynamics specific to post-mining regions.

^{††} GrEnMine (Gravitational Energy Storage in the Post-Mine Areas) project aims to develop novel gravitational energy storage systems located in former mining areas and waste dump sites (<https://grenmine.eu/>)

Table 1. MCA framework: dimensions, weights, correspondence with JTF provisions, instruments, and thresholds

Dimension	Weight	JTF provision	Instrument	Threshold
Socio-political acceptance	15%	Art. 8(a) - institutional commitment under the TJTP	Semi-structured interview A (28 items)	60% support
Community acceptance	25%	Art. 8(b) - public participation	Likert questionnaire L (42 items, $\alpha = 0.87$)	60% positive responses
Market acceptance	20%	Art. 8(e) - private investment	Structured interview I (22 items)	$\geq 3.0/5.0$
Risk perception	15%	Art. 8(g) - environmental risks	Focus group FG-R + questionnaire	$< 2.5/5.0$
Institutional trust	15%	Art. 8(c) - governance quality	Trust questionnaire C (18 items)	$\geq 3.0/5.0$
Perceived equity	10%	Art. 8(d) - worker upskilling	Equity questionnaire E (24 items + 6 open-ended questions)	$\geq 3.5/5.0$

The composite MCA score is calculated as follows:

$$MCA_{so}^c = \sum (S_i \times w_i) / \sum w_i \quad (1)$$

where: S_i represents the normalised dimension score (0-100), and w_i is the corresponding weight. Interpretation: 80-100 = highest priority; 65-79 = recommended with minor conditions; 50-64 = conditional; 35-49 = high risk; < 35 = not recommended.

3.2 Inter-Instrument Triangulation

A key methodological feature of MCA is the inter-instrument triangulation procedure (Instrument GT), which classifies pair wise divergences between dimension scores using a four-level scale (Table 2). Operationally, the procedure computes the absolute pairwise differences between the six normalised dimension scores (0–100) obtained from the independent instruments. The largest of these differences is then classified against the four-level scale in Table 2. The rationale is one of convergent validity: because the instruments measure distinct but related facets of the same underlying social licence, a large divergence indicates that the composite score conceals an internal tension that the aggregate figure alone would mask, whereas concordant scores confirm that the composite is a reliable summary. For the Petrila pilot, the dimension scores ranged from 55 (risk perception) to 72 (socio-political acceptance), a maximum divergence of 17 points, which places the case at Level 2 (partial concordance): the composite score is usable, but the socio-political/risk gap is flagged as the divergence requiring interpretive attention. The thresholds are calibrated against divergence levels documented in the wind-energy sitting literature as predictors of community opposition [9]. Level 1 (≤ 8 points) falls within measurement uncertainty; Level 3 (21–35 points) indicates a structural divergence requiring targeted intervention; and Level 4 (> 35 points) indicates an active conflict that precludes investment.

Table 2. Inter-instrument triangulation: levels, thresholds, and decision implications

Level	Designation	Threshold	Decision implication
1	Full concordance	All differences ≤ 8 points	Proceed - reliable score
2	Partial concordance	Largest difference: 9-20 points	Proceed with conditions - identify the source of divergence
3	Significant divergence	Largest difference: 21-35 points	Investigate - targeted mediation is required
4	Active conflict	Largest difference > 35 points	Defer - social licence negotiation is required

3.3 Data Collection Status

The framework is applied in Romania. Table 3 presents the data collection status as of December 2025. The present paper reports the results for Petrila Hard Coal Mine (Figure 1), Romania, the only site for which the full set of research instruments has been completed. All six instruments were validated in five languages (Romanian, Polish, Greek, Czech and English) to enable identical application across the four pilot regions. Because the Petrila pilot was conducted exclusively within the Romanian former-mining community, only the Romanian-language versions were administered at this stage; the Polish, Greek and Czech versions will be deployed in the forthcoming pilots in Poland, Greece and the Czech Republic.

Table 3. Data collection status by site and instrument (December 2025)

Site	Country	L (n)	A (n)	I(n)	FG-R	E (n)	Status
Petrila	Romania	112	4	3*	2	98	Complete

*below the target of five complete responses; market-acceptance score reported as provisional.



Fig. 1. Petrila Hard Coal Mine (photo: Alexandru Bogye)

4. Pilot results: Petrila living lab

The framework methodology presented in this paper was developed to address socioeconomic issues associated with post-mining land uses and activities, such as RM-GES. As an initial step in validating the proposed methodology, questionnaires were distributed to members of the former mining communities in the Jiu Valley through the Petrila Living Lab, given that Just Transition strategies have already been developed for this area and are currently being partially implemented.

4.1 Site Context

Petrila is a former underground coal mine located in the Jiu Valley, Hunedoara County, Romania. Its main gallery is 3,100 m long and has an inclination of 22°, values that fall within the optimal range for RM-GES implementation (15-25°; >1,500 m) [2]. The mine ceased production in 2015 and is also the subject of a parallel heritage conversion project-the Digital Mining Museum, Deliverable D8.2 of HI-EURECA-PRO. The town has an unemployment rate of approximately 14% according to the 2023 census and is covered by the Hunedoara Territorial Just Transition Plan, with an allocation of EUR 320 million for 2021-2027.

Data were collected between March and November 2025 and comprised 112 questionnaires (Instrument L; 60% completion rate), four interviews with representatives of public authorities and institutions (Instrument A: Petrila Municipality, Hunedoara County Council, West Regional Development Agency, and the University of Petroșani), two focus-group sessions (FG-R; n = 12 and n = 11; 58% former miners and 42% community members), and 98 equity questionnaires (Instrument E). The market-acceptance interviews yielded three complete responses, below the target of five; consequently, the corresponding score remains provisional. The market-acceptance interviews yielded three complete responses, below the target of five; consequently, the corresponding dimension score is reported as provisional and is flagged as such in Table 3. To ensure that this limitation does not distort the overall result, the market-acceptance dimension was included in the sensitivity analysis, and the composite score proved stable (± 4 points) across the six weighting scenarios. The market-acceptance instrument will be re-administered to reach the target sample before the cross-country comparison.

4.2 MCA Scores

The composite score of 66/100 places Petrila in the „recommended with conditions” category. Socio-political acceptance received the highest score (72/100), reflecting active institutional support within the Hunedoara JTF framework. Risk perception received the lowest score (55/100), influenced by concerns regarding structural safety and the potential displacement of industrial heritage, as identified through the focus-group analysis presented in Section 4.4.

Table 4. Petrila: MCA dimension scores and composite score

Dimension	Weight	Normalised score (0-100)	Weighted contribution	Status
Socio-political acceptance	15%	72	10.8	Final
Community acceptance	25%	68	17.0	Final
Market acceptance	20%	61	12.2	Provisional (n = 3)
Risk perception	15%	55	8.25	Final
Institutional trust	15%	64	9.6	Final
Perceived equity	10%	66	6.6	Final
COMPOSITE MCA SCORE	100%	66/100		Recommended with conditions

4.3 Sensitivity Analysis

To assess the robustness of the results to alternative weighting assumptions, Table 5 presents the composite scores for six scenarios covering a range of realistic investor-priority profiles.

Table 5. Petrila: composite MCA scores across six weighting scenarios

Scenario	Soc.-pol.	Comm.	Market	Risk	Trust	Equity	Score	vs. S0
S0 - Default (JTF-balanced)	15%	25%	20%	15%	15%	10%	66	Ref.
S1 - Community-dominant	10%	40%	15%	15%	15%	5%	67	+1
S2 - Institutional	25%	15%	25%	15%	15%	5%	67	+1
S3 - Technical-social (T6.3)	10%	20%	15%	20%	20%	15%	65	-1
S4 - Equal weights	17%	17%	17%	17%	17%	17%	64	-2
S5 - Risk-averse	10%	20%	15%	30%	20%	5%	63	-3

Instruments: L — community-acceptance Likert questionnaire; A — socio-political semi-structured interview; I — market-acceptance structured interview; FG-R — risk-perception focus group; E — perceived-equity questionnaire. The institutional-trust items (Instrument C, 18 items) were administered as a module within the main questionnaire, at the same respondents (n = 112); the institutional-trust sub-scale achieved Cronbach $\alpha = 0.79$. Each instrument corresponds to one MCA dimension (Table 1). Instrument I reached three of the five targeted responses, hence the provisional status of the market-acceptance dimension. The scores across the six scenarios range from 63 to 67 (± 4 points). The “recommended with conditions” classification is maintained for scenarios S0-S3, which cover most realistic investor profiles; however, it becomes marginal under scenarios S4-S5, in which greater weight is assigned to risk perception. This finding directly supports the need for the risk communication intervention described in Section 4.4.

4.4 Focus - Group Analysis: Conditional Acceptance and Industrial Heritage

Thematic coding of the two focus-group sessions (Cohen’s $\kappa = 0.81$) identified three risk narratives: structural risk (71% of participants), economic displacement risk (64%), and heritage displacement risk (52%). Importantly, 68% of participants expressed conditional rather than unconditional acceptance, identifying three main conditions: guarantees of local employment, mentioned by 84% of participants expressing conditional acceptance; explicit co-location of the RM-GES infrastructure with the mining museum rather than its displacement (72%); and the establishment of a community benefit-sharing mechanism (61%).

The finding concerning coexistence with industrial heritage is particularly relevant to project design. Among the 72% of participants who identified heritage coexistence as a condition, 89% stated that dual-use access to the gallery-scheduling RM-GES operations to remain compatible with museum access periods-would shift their acceptance from conditional to unconditional. The engineering assessment confirmed the physical feasibility of dual-use operation at Petrila without structural modifications. This represents a mutually beneficial outcome: co-location with industrial heritage reduces the costs associated with obtaining a social licence while maintaining operational efficiency and may qualify under the JTF provisions concerning cultural heritage.

4.5 Triangulation Analysis

The overall Level 2 classification indicates that there are no active conflicts or irreconcilable divergences at Petrila. The only Level 2 pairing-socio-political acceptance versus risk perception, with a divergence of -17 points-is analytically interpretable and can be addressed through structural measures. The pathway towards securing a social licence is therefore manageable: it requires the operationalisation of commitments, including community benefit agreements and project designs that accommodate coexistence with industrial heritage, rather than persuasion.

Table 6. Petrila: inter-instrument triangulation matrix

Instrument pair	Score 1	Score 2	Divergence	Level	Interpretation
Socio-political (A) vs. community (L)	72	68	-4	1 - Full	Both groups are positive; within measurement uncertainty
Socio-political (A) vs. risk (FG-R)	72	55	-17	2 - Partial	Institutions operate within the JTF framework; the community focuses on tangible risk. Addressable through a benefit agreement
Community (L) vs. equity (E)	68	66	-2	1 - Full	No distributional conflict was identified
Market (I) vs. trust (C)	61	64	+3	1 - Full	Investor and community institutional trust are consistent
Overall: Level 2 - Proceed with conditions			Max.: 17	Level 2	Recommendation: targeted risk communication + community benefit agreement

5. Discussion

The MCA framework contributes to the social acceptance literature in three respects. First, the direct alignment of the MCA dimensions with the JTF regulatory provisions (Table 1) creates a dual-purpose assessment instrument: it simultaneously generates evidence of social acceptance and documentation supporting eligibility for JTF co-financing, thereby reducing the transaction costs associated with integrating social research into investment processes. This alignment is particularly relevant in the context of the Jiu Valley, where the Hunedoara JTF represents the principal financing pathway for RM-GES capital expenditure (CAPEX).

Second, the inter-instrument triangulation procedure identifies the specific stakeholder pairing-institutions versus the community-and the analytical domain-risk perception-underlying the main social-licence challenge at Petrila. This level of precision cannot be achieved through aggregate scoring methods and directly supports the design of targeted interventions: the risk communication and benefit-agreement strategy addresses the divergence between the community and institutional actors rather than a diffuse form of „social opposition”.

Third, the finding concerning coexistence with industrial heritage represents an empirical contribution specific to the post-mining context. Recognition of industrial heritage facilitates acceptance when the project design explicitly preserves it. The shift from conditional to unconditional acceptance observed among 89% of participants concerned about heritage translates into a measurable reduction in social-licence costs. This reduction should be incorporated into the economic assessment of RM-GES projects and the supporting narratives of JTF applications concerning heritage sites.

The present analysis has several limitations: the pilot data originate from a single site; the confirmatory factor analysis (CFA) of Instrument L for the full sample ($n = 112$) is still in progress; and the market-acceptance score remains provisional ($n = 3$). Nevertheless, applying the framework methodology developed for the Petrila Living Lab pilot enabled the aggregation of reliable results, supporting the coherence, validity, and suitability of the selected criteria and their assigned weights. The complete GrEnMine dataset, covering eleven sites and scheduled for project month 36 in 2026, will enable more generalizable conclusions to be drawn.

6. Conclusions

This paper presented the MCA framework for assessing the social acceptance of RM-GES and its pilot application at Petrila in the Jiu Valley. The evidence supports three main conclusions:

1. The composite score of 66/100 obtained for Petrila remains stable across realistic weighting scenarios (± 4 points) and indicates a manageable pathway towards securing a social licence, classified as “recommended with conditions”, rather than an impasse driven by opposition.

2. The principal social-licence challenge is a Level 2 divergence (partial concordance) between institutional and community stakeholders regarding risk perception. This divergence can be addressed structurally through community benefit agreements and project designs that accommodate coexistence with industrial heritage.

3. Co-location with industrial infrastructure represents an original empirical finding with potential applicability to the eleven sites in the GrEnMine dataset that have active heritage programmes. Among heritage-concerned participants at Petrila, 89% shifted from conditional to unconditional acceptance when presented with a dual-use gallery design.

The project's complete dataset and the complementary site-selection tool will provide the full empirical basis for policy recommendations concerning the conditions for RM-GES deployment across European post-mining regions.

Acknowledgements

This work was supported by the Research Fund for Coal and Steel (RFCS), European Commission, Grant Agreement No. RFCS-2023-01-RPJ (GrEnMINE project). The authors thank the 135 participants at the Petrila Living Lab and the Municipality of Petrila for institutional support.

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