

A Weighted PESTLE Diagnostic of Critical Raw Materials Sector Development in North Macedonia: Quantifying Macro-Environmental Constraints for Integration into European Union Value Chains

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Abstract

Background

The European Union's Critical Raw Materials Act has made the security and governance of critical raw materials (CRM) supply central to industrial policy and has raised the strategic value of mineral-bearing candidate countries such as North Macedonia. Recent PESTLE-based assessments of the country's CRM sector have characterised its six dimensions – political, economic, social, technological, legal and environmental – qualitatively and, at most, through an unweighted enabling-versus-constraint readiness scoring, yet none assigns explicit relative weights across the dimensions. This study introduces a transparent, evidence-anchored weighting procedure to identify which macro-environmental dimensions most constrain the sector's integration into European value chains.

Results

Category weights were derived from a three-criterion rubric – determinacy of sector outcomes, bindingness in the documented evidence, and coupling to European Union accession and Critical Raw Materials Act conditionality. Each dimension received a readiness score anchored in traceable peer-reviewed and institutional sources, and the two were combined into a Weighted Readiness Index (WRI) and a constraint-gap decomposition. The derived weights rank the legal (20.5%), political (19.2%) and environmental (17.8%) dimensions above the economic and technological (15.1% each) and social (12.3%) dimensions. The composite WRI is 47.4% of the maximum attainable score, indicating a sector materially engaged with European value chains yet well below readiness. Decomposing the shortfall reorders the priorities: the environmental (20.3%), legal (19.5%) and technological (17.2%) dimensions contribute the largest shares of the gap, because high-weight dimensions coincide with low documented performance. A sensitivity test against published energy-sector weights confirms that the composite is robust (47–48%) while the constraint ranking is weighting-dependent.

Conclusions

The binding constraints on the sector are governance, environmental enforcement and processing capability rather than geological endowment. The most tractable near-term pathway couples remediation of legacy extractive waste with European Union-aligned secondary CRM recovery. The weighting method is transparent and transferable, offering a reproducible way to compare candidate countries and to track a country's readiness over time.

1. Background

The decarbonisation and digitalisation of the European economy have converted access to critical raw materials (CRM) from a sectoral concern into a question of strategic autonomy. The European Union

responded with Regulation (EU) 2024/1252, the Critical Raw Materials Act (CRMA), which designates 17 strategic and 34 critical raw materials and fixes binding 2030 benchmarks for the Union: at least 10% of annual demand met from domestic extraction, 40% from domestic processing and 25% from recycled content, together with a ceiling of 65% on reliance on any single third country for each strategic material [1]. Because these benchmarks are a deliberate intervention in market structure, they reshape the strategic value of mineral-bearing territories on the Union's periphery, including the candidate countries of the Western Balkans.

The conceptual apparatus that underpins criticality – the joint assessment of supply risk and economic importance, and the dependence of many high-technology elements on by-product recovery – is now well established [2, 3]. What remains comparatively underdeveloped is the translation of this apparatus into operational, country-level diagnostics for the territories that the CRMA implicitly enrolls as potential suppliers. North Macedonia is an instructive case. It is a landlocked candidate country with a long mining tradition, established production of copper, lead, zinc, silver and gold, a documented stock of legacy extractive waste, and an accession process that exposes its mineral sector to the full weight of the EU environmental and rule-of-law *acquis*.

A recurring analytical choice in prior macro-environmental work on the country – and on resource sectors more broadly – is the PESTLE framework, which organises the external environment into political, economic, social, technological, legal and environmental dimensions. PESTLE has been applied to mining and energy contexts in developing and transition economies [4, 5, 6], and in a series of recent studies to North Macedonia's CRM sector specifically [7, 8, 9, 10]. Across those applications, however, the six dimensions are almost always treated as analytically equal: each receives a narrative treatment – or, at most, an unweighted readiness score – and the relative importance of, say, legal alignment versus social acceptance is left implicit. This is a genuine limitation, because policy prioritisation under resource constraints requires precisely the comparative ordering that an unweighted framework withholds.

This paper makes that ordering explicit. Its contribution is methodological as well as empirical: it introduces a transparent weighting of the PESTLE dimensions for the specific context of CRM sector development in a candidate country, anchors a readiness score for each dimension in traceable evidence, and combines the two into a composite Weighted Readiness Index and an explicit decomposition of where the readiness shortfall actually originates. The result is a reproducible diagnostic that distinguishes the dimensions that matter most in principle from those that constrain the sector most in practice – a distinction with direct consequences for sequencing reform.

2. Prior work and analytical gap

2.1 PESTLE weighting in resource and transition sectors

The argument for weighting PESTLE dimensions is not new; it is, rather, inconsistently applied. Two strands of the resource-sector literature are directly relevant. Kangwa and Mutambo [5], assessing the potential for mining low-grade copper deposits in Zambia, decomposed each PESTLE dimension into sub-factors and obtained averaged ratings on a numerical scale from a panel of mining-sector respondents, allowing the dimensions to be compared rather than merely described. Soares et al. [6], studying renewable energy business models in Mozambique, asked experts to distribute percentage weights across the six categories and reported a clear hierarchy: political (24%) and economic (23%) dimensions together accounted for almost half of the collective weight, followed by social (16%), technological (15%) and legal (13%), with the environmental dimension lowest at 9%. They interpreted this as characteristic of developing-country settings, where political will and capital availability gate sector development. Dalirazar and Sabzi [4], analysing barriers to sustainable building across several countries, similarly demonstrated that the framework can carry quantitative weight rather than serving only as a descriptive checklist.

Two implications follow. First, weighting is methodologically legitimate and has precedent in exactly the mining and transition contexts at issue. Second, the weights are context-dependent: the Mozambican energy-sector hierarchy cannot be transposed wholesale to a candidate-country CRM sector, where accession conditionality elevates the legal and environmental dimensions in a way that a domestic energy market does not. The Mozambican result is therefore used here not as a template but as an external benchmark against which a CRM-specific weighting can be tested.

2.2 North Macedonia's mineral endowment and waste legacy

North Macedonia's geology is structured by five principal tectonic units, of which the Serbo-Macedonian Massif and the Vardar Zone host the country's economically significant base-metal mineralisation [11]. Current output is concentrated in copper at the Bučim and Borov Dol porphyry systems and in lead–zinc–silver at Sasa, Toranica and Zletovo; reported annual production is of the order of 43,490 t of lead, 31,040 t of zinc and approximately 7,230 t of copper, together with 593 kg of gold and 17,880 kg of silver, for a total non-ferrous metal output of 81,761 t [12]. The country thus already participates in European value chains, but at the upstream, concentrate stage, with no documented domestic hydrometallurgical refining capacity.

The country's less visible asset is its inventory of secondary resources. Preliminary chemical and mineralogical characterisation of tailings from base-metal sulfide deposits places the Bučim copper tailings at roughly 125 Mt and reports elevated lead (~ 4,640 ppm), zinc (~ 4,020 ppm) and indium (~ 9.1 ppm) in the Probištip tailings, gallium and germanium in the Sasa lead–zinc system, and extreme arsenic and antimony grades (both exceeding 10,000 ppm) at Lojane; the characterised sites together total approximately 175.5 Mt [13]. The lead–zinc slag deposit of the former MHK Zletovo smelter at Veles carries an average of 9.6% zinc (a potential ~ 120,000 t), 2.4% lead (~ 29,000 t) and recoverable quantities of indium, antimony and other elements [14]. A regional assessment confirms that such

mining and metallurgical waste constitutes a credible secondary source of metals across the West Balkans [15]. Two caveats discipline any enthusiasm: indium, although present in these datasets, is not listed in the CRMA statutory annexes, whereas antimony is a listed critical material, so the supply-security relevance of a given site depends on which elements it actually carries [1, 13].

The same waste legacy is simultaneously an environmental liability. Arsenic and antimony at the abandoned Lojane site are mobile and have been identified as a contamination hotspot [16]; hexavalent chromium from the Jugohrom–Jegunovce industrial dump has contaminated shallow groundwater at concentrations reaching 132.98 mg/l against a maximum allowable concentration of 0.01 mg/l, a legacy of plant operation between 1955 and 1994 [17]. This dual character — liability and resource — is the analytical pivot of the sector and is treated explicitly in the weighting below.

2.3 The analytical gap

The most developed prior analysis of the country's CRM sector supplements its qualitative PESTLE with a semi-quantitative readiness scoring, rating each dimension's enabling strength and constraint severity on a 1–5 scale and taking their difference as a net readiness signal [10]; the companion assessments remain qualitative [7, 8, 9]. Useful as these are for inventorying the sector's constraints and opportunities, they share one decisive feature: they treat the six dimensions as equally weighted. Even the enabling-minus-constraint score assigns no relative importance across dimensions, so a severe constraint in a peripheral dimension counts for as much as one in a decisive dimension, and the analysis cannot indicate where a given readiness shortfall matters most. This study departs from that convention in three connected ways: it derives explicit category weights from a transparent rubric; it combines those weights with readiness scores into a single comparable composite; and it uses the weights to separate a dimension's importance from the size of its readiness shortfall — the distinction developed in Section 4.

3. Materials and methods

3.1 Evidence base and citation discipline

The analysis relies exclusively on traceable sources: peer-reviewed scientific and technical publications, an EU legislative text, and a policy brief from an established research institute. No primary data were collected, and no claim is admitted unless it can be attributed to one of these sources. Production and geological baselines are drawn from the geological and mining-data literature [11, 12]; tailings and slag characterisations from peer-reviewed geochemical studies [13, 14, 15]; contamination evidence from site-specific environmental investigations [16, 17]; legislative and circular-economy context from the relevant analysis [18]; and the regional cooperation and resource-efficiency framing from recent institutional and comparative work [19, 20, 21, 22]. The CRMA itself supplies the benchmark architecture [1].

3.2 Category weighting rubric

Rather than assert weights, the study derives them from a three-criterion rubric applied consistently to each dimension. Each criterion is scored on an integer scale from 1 (low) to 5 (high): (i) determinacy — the degree to which the dimension governs whether CRM sector development can occur at all, irrespective of the others; (ii) bindingness — the severity of the constraint actually documented for North Macedonia in the cited evidence; and (iii) accession coupling — the tightness of the dimension's link to EU accession conditionality and CRMA trusted-supplier expectations, which in a candidate country convert external requirements into domestic obligations.

For each dimension the three criterion scores are summed, and the category weight is the dimension's sum expressed as a share of the total across all dimensions. This procedure is transparent and reproducible: a reader who disagrees with a single cell can recompute the weights. The criterion scores reflect a structured expert assessment informed by the cited evidence and by the weighting precedents in Section 2.1; they are not survey-derived, and Section 5.3 treats this explicitly as a limitation and as the natural target of future elicitation work.

3.3 Readiness scoring and composite indices

Each dimension is then assigned a readiness score R_i on a 1–5 scale, where 5 denotes a fully enabling condition with no material constraint, 3 denotes a partially enabling condition that neither strongly enables nor severely constrains the sector, and 1 denotes a severe binding constraint; intermediate half-point values are permitted. The score is anchored in the documented evidence for that dimension, summarised in Section 4. Two composite measures follow. The Weighted Readiness Index is the weighted mean of the readiness scores, $WRI = \sum w_i R_i$, reported both on the 1–5 scale and as a percentage of the maximum attainable score of 5. The constraint-gap contribution of each dimension is $G_i = w_i(5 - R_i)$, and its share of the total shortfall, $G_i / \sum G_i$, identifies where the readiness deficit actually originates. The distinction between the weight w_i (importance) and the gap share (where the sector underperforms relative to its importance) is the central analytical device of the paper.

3.4 Declaration of generative AI use

In preparing this manuscript, the authors used a large language model (Anthropic Claude) to assist with drafting, structuring and language editing of the text and with assembling and formatting the analysis. The weighting rubric, the selection and interpretation of sources, all analytical decisions, and the final content were determined and verified by the authors, who reviewed and edited all text and take full responsibility for the integrity and accuracy of the work. No statement was retained without verification against the cited primary sources.

4. Results

4.1 Derived category weights

Table 1 reports the rubric scores and the resulting weights. The legal dimension receives the highest weight (20.5%) because permitting integrity, reserve classification and transposition of the extractive-waste and water acquis are simultaneously highly determinant of sector outcomes, severely constrained in practice, and tightly coupled to accession. The political dimension follows closely (19.2%): the accession trajectory and the state's decisions on concessions gate investment, and the dimension is maximally accession-coupled. The environmental dimension is third (17.8%), reflecting the unusually severe documented contamination legacy. The economic and technological dimensions are equal (15.1% each), and the social dimension is lowest (12.3%) – not because social acceptance is unimportant, but because its determinacy and accession coupling are lower than those of the governance dimensions.

Table 1
Category weighting rubric and derived weights (criterion scale 1–5)

PESTLE dimension	Determinacy	Bindingness	Accession coupling	Sum	Weight
Political	5	4	5	14	19.2%
Economic	4	4	3	11	15.1%
Social	3	4	2	9	12.3%
Technological	4	4	3	11	15.1%
Legal	5	5	5	15	20.5%
Environmental	4	5	4	13	17.8%
Total	—	—	—	73	100%

4.2 Dimension-by-dimension evidence and readiness scores

Political (R = 3.0). North Macedonia has been an EU candidate since 2005, and the accession process supplies a strong, externally enforced incentive for regulatory convergence; the Union's explicit interest in cooperating with the Western Balkans on secondary raw materials reinforces this pull [22]. The principal weakness is that this cooperation is presently framed largely through non-binding memoranda rather than embedded in the monitored chapters of the accession framework, which limits its credibility and enforceability [22]. The dimension is therefore enabling but only moderately so.

Economic (R = 2.5). The sector is a functioning upstream exporter, with substantial lead, zinc, copper, silver and gold output directed into European industry [12]. Against this, the absence of domestic refining means most value is captured downstream outside the country, mining's share of GDP is modest, and capital for processing or recovery investment is scarce; regional analyses identify financing and the lack of internationally recognised resource reporting as persistent barriers to attracting investment [19, 20]. The dimension is partly enabling but structurally constrained at the value-capture stage.

Social (R = 2.0). Documented contamination with direct human-health implications – hexavalent chromium in drinking-water aquifers near Jugohrom–Jegunovce and arsenic–antimony dispersal at Lojane – erodes the social licence on which any expansion or reprocessing depends [16, 17]. Combined with the skills and workforce challenges typical of the regional mining sector, this places the dimension in the constrained range.

Technological (R = 2.0). Beneficiation and flotation capability exists at the operating mines, but there is no documented in-country hydrometallurgical or intermediate processing capacity, and the recovery technologies relevant to secondary resources remain at laboratory or pilot maturity. The mining sector’s general difficulty in absorbing disruptive innovation and the non-alignment of resource and reserve reporting with international codes further constrain the dimension [20, 21]. Readiness is low.

Legal (R = 2.5). The relevant EU instruments – the Mining Waste Directive, the Waste Framework Directive and its end-of-waste logic – define the target state and create a credible path to a zero-waste, secondary-resource model for which North Macedonia is assessed to have strong potential [18]. Realisation is impeded, however, by incomplete transposition, lengthy and fragmented permitting, and administrative obstacles to recognising waste as a secondary raw material [18], with the environment chapter of the *acquis* still in progress [22]. The framework is favourable in principle but only partly operative.

Environmental (R = 2.0). The contamination legacy is extensive and quantified: hexavalent chromium in groundwater far exceeding permissible limits [17], mobile arsenic and antimony at an abandoned site identified as a hotspot [16], and large volumes of unprotected or partly contained tailings and slag [13, 14]. Energy-intensive processing compounds the footprint. The countervailing opportunity – financing remediation partly through recovery of valuable metals [13, 15, 18] – is real but unrealised, leaving present readiness low.

4.3 Weighted Readiness Index

Table 2 combines the weights of Table 1 with the readiness scores of Section 4.2. The Weighted Readiness Index is 2.37 on the 1–5 scale, equivalent to 47.4% of the maximum attainable score. The interpretation is that North Macedonia is roughly halfway to a fully enabling environment for CRM sector development: materially engaged with European value chains, but with no dimension reaching the enabling range. The political dimension sits at the mid-point of the scale, while the remaining five dimensions cluster in the constrained band.

Table 2
Weighted Readiness Index (WRI) computation

PESTLE dimension	Weight w_i	Readiness R_i (1–5)	Weighted score $w_i R_i$	Contribution to WRI
Political	0.192	3.0	0.575	24.3%
Economic	0.151	2.5	0.377	15.9%
Social	0.123	2.0	0.247	10.4%
Technological	0.151	2.0	0.301	12.7%
Legal	0.205	2.5	0.514	21.7%
Environmental	0.178	2.0	0.356	15.0%
WRI (total)	1.000	—	2.37 / 5	47.4%
4.4 Where the readiness shortfall originates				

The WRI conceals as much as it reveals, because a dimension can be important yet adequately provided for, or unimportant yet severely deficient. Table 3 therefore decomposes the readiness shortfall using $G_i = w_i(5 - R_i)$. The ranking changes. Although the legal and political dimensions carry the highest weights, the largest contributions to the readiness gap come from the environmental (20.3%), legal (19.5%) and technological (17.2%) dimensions, because these combine substantial weight with low documented performance. The political dimension, despite its high weight, contributes less to the gap (14.6%) because its readiness is comparatively higher. This reordering is the practical output of the weighting exercise: it indicates that environmental remediation and enforcement, legal and permitting reform, and processing-and-recovery capability – in that order – are where marginal effort yields the greatest improvement in overall readiness. Figure 1 makes the divergence explicit, setting each dimension's importance weight beside its share of the readiness gap: for the political, economic and legal dimensions the weight exceeds the gap share, so they are better provided for than their importance would demand, whereas for the technological, environmental and social dimensions the gap share exceeds the weight, so they are more deficient than their importance alone would suggest.

Table 3
Constraint-gap decomposition and resulting priority ranking

PESTLE dimension	Weight w_i	Gap $G_i = w_i(5-R_i)$	Share of gap	Priority rank
Environmental	0.178	0.534	20.3%	1
Legal	0.205	0.514	19.5%	2
Technological	0.151	0.452	17.2%	3
Political	0.192	0.384	14.6%	4
Economic	0.151	0.377	14.3%	5
Social	0.123	0.370	14.1%	6
Total	1.000	2.63	100%	—

4.5 Sensitivity to the weighting scheme

To test robustness, the same readiness scores were combined with the published developing-country energy-sector weights of Soares et al. [6] (political 24%, economic 23%, social 16%, technological 15%, legal 13%, environmental 9%). The resulting index is 2.42 on the 1–5 scale (48.4%), within one percentage point of the value obtained with the CRM-specific weights (Table 4). The composite readiness is therefore robust to the choice of weighting scheme. The constraint ranking, by contrast, is not: under the energy-sector weights the low environmental weight (9%) demotes the environmental dimension in the gap decomposition, whereas under the CRM-specific weights it ranks first. This contrast is itself a finding. It shows that the substantive difference a candidate-country CRM weighting makes is not to the headline readiness figure but to the prioritisation of reform — and that applying an energy-sector default would systematically understate the environmental and legal dimensions that the documented evidence identifies as most binding.

Table 4
Sensitivity of the composite index to the weighting scheme

Weighting scheme	WRI (1–5)	WRI (% of maximum)
CRM-specific weights (this study)	2.37	47.4%
Energy-sector weights (Soares et al. 2023; benchmark)	2.42	48.4%

5. Discussion

5.1 Importance versus deficiency

The central result is the divergence between the weight ranking (legal, political, environmental, then economic and technological, then social) and the gap ranking (environmental, legal, technological, then

political, economic, social). The divergence arises because the dimensions in which North Macedonia performs least well are not uniformly the most important ones, and vice versa. The political dimension is highly important but comparatively well provided for, because the accession process supplies an exogenous reform incentive; the environmental dimension is slightly less weighted but far more deficient, because the contamination legacy is both severe and largely unaddressed. A purely qualitative PESTLE treatment, which lists constraints without weighting them, cannot surface this distinction, and would tend to give equal narrative emphasis to a well-supported political environment and a severely deficient environmental one.

5.2 Coupling between dimensions

The weighting also clarifies why the dimensions cannot be addressed in isolation. The environmental and legal gaps are coupled: remediation of legacy waste and recognition of that waste as a secondary raw material both depend on transposing and enforcing the extractive-waste and end-of-waste provisions of the *acquis* [18], so legal reform is a precondition for closing the environmental gap rather than an independent track. The technological and economic gaps are similarly coupled: the absence of refining and recovery capability is simultaneously a technological deficit and the mechanism by which value leaks downstream [12, 19]. And the social gap is downstream of the environmental one, because the contamination record is precisely what depresses the social licence [16, 17]. The practical implication is that the highest-ranked intervention – environmental remediation and enforcement – is also the one with the most favourable spillovers, since it simultaneously relieves the social constraint and, by establishing the conditions for compliant reprocessing, contributes to the economic and technological dimensions.

5.3 Limitations

Three limitations bound the interpretation. First, the criterion scores and readiness scores reflect a structured expert judgement informed by the cited evidence rather than a stakeholder survey; the rubric is transparent and recomputable, but the inputs are not yet validated against a panel of respondents in the manner of the Zambian and Mozambican studies [5, 6]. Second, the readiness scores are coarse by design; a finer scale or sub-factor decomposition would increase resolution at the cost of demanding evidence that, for some dimensions, does not yet exist at the country level. Third, several quantitative figures – notably current trade values and the operational status of individual assets – evolve faster than the peer-reviewed record and would need to be refreshed from primary statistics before the diagnostic is used operationally. None of these limitations affects the central methodological claim: that weighting changes the prioritisation in a way an unweighted framework cannot capture.

5.4 Policy implications

The gap decomposition translates directly into a sequencing of reform. The first priority is a risk-based programme of remediation and enforcement at the documented high-hazard legacy sites, designed from the outset to permit recovery of valuable metals where this produces a net environmental benefit, so that remediation is partly self-financing [13, 15, 18]. The second is legal and administrative reform to

transpose and enforce the extractive-waste and water acquis and to streamline permitting, which is both an accession requirement and the enabling condition for compliant reprocessing [18, 22]. The third is targeted investment in processing and recovery capability, linked to EU instruments and to the adoption of internationally recognised resource-reporting standards that the regional literature identifies as a precondition for investment [19, 20, 21]. Embedding raw-materials cooperation within the monitored chapters of the accession framework, rather than in non-binding memoranda, would convert the favourable political dimension into durable leverage across the others [22].

6. Conclusions

This study replaced the equal-weight convention of prior macro-environmental analyses of North Macedonia's critical raw materials sector with a transparent, evidence-anchored weighting of the six PESTLE dimensions. The derived weights place the legal, political and environmental dimensions above the economic, technological and social ones, and the composite Weighted Readiness Index of 47.4% locates the country roughly midway to a fully enabling environment — a result shown to be robust to the choice of weighting scheme. The decisive contribution is the decomposition of the readiness shortfall, which reorders the priorities and identifies the environmental, legal and technological dimensions as the largest contributors to the gap, because in those dimensions high importance coincides with low documented performance.

The policy reading is consistent with, but sharper than, the qualitative consensus: the binding constraints on the sector are governance, environmental enforcement and processing capability rather than geological endowment, and the most tractable near-term pathway couples remediation of the legacy extractive-waste estate with EU-aligned secondary CRM recovery. The weighting method is portable: applied with locally elicited criterion and readiness scores, it offers a reproducible way to compare candidate countries and to track a single country's readiness over time. Validating the present scores through structured stakeholder elicitation, and extending the diagnostic comparatively across the Western Balkans, are the natural next steps.

Abbreviations

CRM
critical raw materials
CRMA
Critical Raw Materials Act
EU
European Union
PESTLE
political, economic, social, technological, legal and environmental
WRI
Weighted Readiness Index.

Declarations

Ethics approval and consent to participate

Not applicable. This study did not involve human participants, human data or tissue, or animals.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

Conceptualization, methodology, formal analysis, investigation, data curation, and writing — original draft were performed by D. P. Writing — review and editing, validation, and supervision were performed by S.M. M.H-N. contributed to the methodology and resources, provided validation of the environmental and legal assessments, and reviewed and edited the manuscript. This work forms part of the doctoral research of D.P., who is the principal author. All authors read and approved the final manuscript.

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Availability of data and materials

All data analysed in this study are from previously published, publicly available sources, which are cited in the article and listed in the references. No new datasets were generated or analysed during the current study.

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Figures

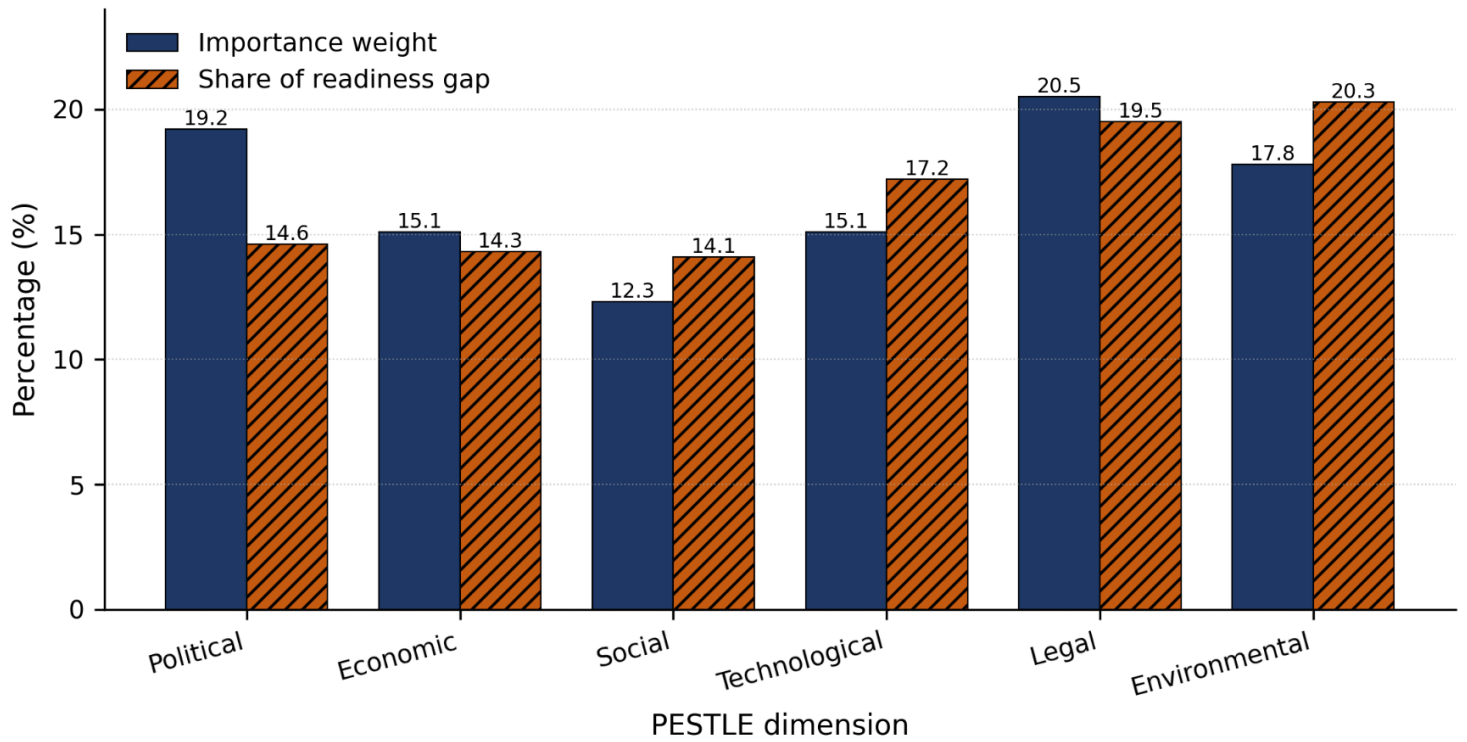


Figure 1

Importance weight of each PESTLE dimension (dark bars) compared with its share of the overall readiness gap (hatched bars). Dimensions where the weight bar exceeds the gap bar are better provided for than their importance requires; dimensions where the gap bar is higher are comparatively more deficient