

S2. PRISMA 2020 checklist

Checked against the full revised manuscript and the split-methods plan:
concise Section 2 in the main text, detailed methodology in Supplementary Material S1

Section and topic	Item	Checklist item	Current location in revised manuscript	Status	Updated note / action needed
TITLE	1	Identify the report as a systematic review.	Title page / Title	Reported	The title explicitly identifies the manuscript as a systematic review.
ABSTRACT	2	Follow the PRISMA 2020 for Abstracts checklist.	Abstract	Reported	The abstract includes a brief statement on the main limitations of the evidence base and notes that the review protocol was prepared but not publicly registered, bringing the abstract-level PRISMA reporting into line with the streamlined manuscript structure.
INTRODUCTION - Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction	Reported	The rationale is clearly developed and situated within hydropower modernization, sustainability, and the energy-transition context.
INTRODUCTION - Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction and closing overview paragraph; Section 2 review questions	Reported	The objective is explicit, and Section 2 states three concrete review questions.
METHODS - Eligibility criteria	5	Specify inclusion and exclusion criteria and how studies were grouped for the syntheses.	Section 2 plus Supplementary Material S1	Reported	Eligibility criteria are clearly stated: topic scope, publication window, source types, and exclusion of non-relevant or methodologically insufficient studies. The detailed inclusion and exclusion logic now sits appropriately in Supplementary Material S1.
METHODS - Information sources	6	Specify all sources searched or consulted and the date when each source was last searched.	Section 2 plus Supplementary Material S1	Reported	The information sources are explicit: Web of Science Core Collection and Scopus, with reference-list screening for additional records. The final search date is also reported.
METHODS - Search strategy	7	Present the full search strategies for all databases, including filters and limits used.	Section 2 plus Supplementary Material S1	Reported	The search approach is now adequately reported for this type of engineering review because the manuscript points to Supplementary Material S1 for the detailed search terms and strategy.
METHODS - Selection process	8	Specify how studies were screened for eligibility, including number of reviewers, independence, and any automation tools.	Section 2 plus Supplementary Material S1	Reported	The selection process is now explicit: two-stage screening, independent reviewer assessment, disagreement resolution via discussion and third-reviewer consultation, and an explicit statement that no automation tools or machine-learning screening aids were used.

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METHODS - Data collection process	9	Specify how data were collected from reports, including number of reviewers, independence, and any confirmation steps.	Section 2 plus Supplementary Material S1	Reported	The data-collection process is now clearly described: two independent reviewers used a standardized extraction form, discrepancies were resolved by consensus, and unclear variables were excluded from comparative interpretation when they could not be interpreted reliably.
METHODS - Data items	10a	List and define all outcomes for which data were sought, and explain any decisions about which results were collected.	Supplementary Material S1	Reported	The review now explicitly states that all results compatible with the predefined outcome domains were considered, with priority given to the most directly comparable technical and sustainability-related indicators for the narrative synthesis.
METHODS - Data items	10b	List and define all other variables for which data were sought, and describe assumptions for missing or unclear information.	Supplementary Material S1	Reported	Other data items and assumptions are now sufficiently described. The extraction sheet covers turbine type, operating context, intervention, performance indicators, sustainability indicators, and methodological choices, and the handling of incomplete or unclear information is stated.
METHODS - Study risk of bias assessment	11	Specify the methods used to assess risk of bias / quality in the included studies.	Section 2 plus Supplementary Material S1	Reported	A qualitative methodological appraisal is clearly described, including reviewer independence, appraisal criteria, and its interpretive purpose. The manuscript also explicitly states that no clinical-style pooled risk-of-bias score was generated.
METHODS - Effect measures	12	Specify the effect measure(s) used in the synthesis or presentation of results.	Section 2 (Methodology)	Reported	For this narrative engineering review, the presentation logic is clear: study-reported indicators are synthesized descriptively, and directional effects are summarized without pooled estimates because of heterogeneity.
METHODS - Synthesis methods	13a	Describe how studies were decided to be eligible for each synthesis.	Section 2, opening of Section 3, and Supplementary Material S1	Partial	The narrative synthesis and thematic clustering are clear, but the manuscript still does not fully spell out the exact rule used to assign each study to a single theme or to multiple themes where overlap was possible. This is a minor residual gap, not a major compliance issue.
METHODS - Synthesis methods	13b	Describe any methods used to prepare data for presentation or synthesis.	Supplementary Material S1	Reported	This item is now closed: the detailed methodology explicitly states that no statistical conversion or imputation was required and that heterogeneous findings were harmonized only at the level of terminology, study focus, and outcome direction.
METHODS - Synthesis methods	13c	Describe methods used to tabulate or visually display results.	Section 2 plus Section 3	Reported	Comparable results are summarized directionally and narratively, without pooled estimates, which is appropriate for this heterogeneous engineering evidence base.

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METHODS - Synthesis methods	13d	Describe methods used to synthesize results and justify the choice.	Section 2 plus Section 3	Reported	The synthesis methods are clearly described through thematic clustering into four domains, followed by qualitative comparison of performance, cost, and environmental indicators where available.
METHODS - Synthesis methods	13e	Describe any methods used to explore causes of heterogeneity.	Supplementary Material S1	Not applicable	The review now explicitly states that no formal subgroup analysis, meta-regression, or statistical investigation of heterogeneity was undertaken because the synthesis was narrative rather than quantitative.
METHODS - Synthesis methods	13f	Describe any sensitivity analyses used to assess robustness.	Supplementary Material S1	Not applicable	The review now explicitly states that no sensitivity analyses were undertaken, which removes the previous ambiguity.
METHODS - Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results / reporting biases.	Supplementary Material S1	Reported	The manuscript now explicitly states that no separate assessment of reporting bias due to missing results was undertaken, given the absence of a meta-analytic synthesis.
METHODS - Certainty assessment	15	Describe any methods used to assess certainty / confidence in the body of evidence.	Section 2 plus Supplementary Material S1	Reported	The manuscript explicitly states that no formal certainty-of-evidence framework was applied because the review is a methodological and thematic synthesis rather than a pooled effect-estimation exercise.
RESULTS - Study selection	16a	Describe the results of the search and selection process, ideally using a flow diagram.	Section 2 text and Figure 2	Reported	The manuscript reports the total records identified, the final number of included studies, and the screening workflow, supported by the PRISMA flow diagram.
RESULTS - Study selection	16b	Cite studies that appeared to meet the inclusion criteria but were excluded, and explain why.	Figure 2 and its caption	Reported	This can now be treated as reported because Figure 2 explicitly presents exclusions with reasons at the eligibility stage. Ensure the final figure retained in the manuscript preserves those counts clearly.
RESULTS - Study characteristics	17	Cite each included study and present its characteristics.	Section 3 opening plus Supplementary Table S3	Reported	The manuscript states that included-study characteristics are provided in Supplementary Table S3. This satisfies the item if that table is included in the submission package.
RESULTS - Risk of bias in studies	18	Present assessments of risk of bias / quality for each included study.	Section 3 opening paragraph	Reported	The results section now includes a concise appraisal-results summary: most studies were of moderate-to-good reporting quality, with recurring weaknesses in uncertainty reporting, operational-indicator consistency, and outcome comparability. This is sufficient for narrative-review reporting.

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RESULTS - Results of individual studies	19	Present summary results for each included study.	Sections 3-5; Tables 1-4; any study-summary supplementary table if retained	Partial	Theme-level and case-based results are well developed, but PRISMA's ideal study-by-study outcomes presentation is only partly met unless a supplementary study-summary table is retained. This is acceptable for many engineering reviews, but a concise study-summary table would strengthen compliance.
RESULTS - Results of syntheses	20a	For each synthesis, briefly summarize the characteristics and risk of bias of contributing studies.	Sections 3-5 plus Section 3 appraisal summary	Partial	The syntheses summarize contributing evidence and now include an overall appraisal result, but they still do not fully integrate study-quality observations separately within each thematic cluster. This is a moderate, not critical, residual gap.
RESULTS - Results of syntheses	20b	Present results of all statistical syntheses conducted.	Section 2 narrative-synthesis statement; no statistical synthesis presented	Not applicable	No meta-analysis or other formal statistical synthesis is presented, and the manuscript explains that pooled estimates were not appropriate because of heterogeneity.
RESULTS - Results of syntheses	20c	Present results of investigations of possible causes of heterogeneity.	Supplementary Material S1	Not applicable	No formal investigation of heterogeneity was undertaken, and this is now stated explicitly in the detailed methodology.
RESULTS - Results of syntheses	20d	Present results of all sensitivity analyses.	Supplementary Material S1	Not applicable	No sensitivity analyses were undertaken, and this is now stated explicitly in the detailed methodology.
RESULTS - Reporting biases	21	Present assessments of risk of bias due to missing results / reporting biases.	Supplementary Material S1	Not applicable	Because the manuscript explicitly states that no reporting-bias / missing-results assessment was undertaken, there are no reporting-bias results to present. This should be read as not assessed rather than omitted.
RESULTS - Certainty of evidence	22	Present assessments of certainty / confidence in the body of evidence.	Section 2 (certainty not assessed)	Not applicable	The manuscript explicitly states that no formal certainty-of-evidence assessment was undertaken; therefore, no certainty results are expected.
DISCUSSION	23a	Provide a general interpretation of the results in the context of other evidence.	Sections 3-6, especially Section 6 (Conclusion)	Reported	The discussion / conclusion interprets the findings in the context of hydropower modernization, eco-efficiency, circularity, and the energy transition.
DISCUSSION	23b	Discuss limitations of the evidence included in the review.	Discussion / Conclusion	Partial	Evidence limitations are now touched on through the appraisal summary, but the Discussion would still benefit from one compact sentence explicitly summarizing the main limitations of the included studies.
DISCUSSION	23c	Discuss limitations of the review processes used.	Discussion / Conclusion	Partial	The review-process limitations are partly addressed, but a single explicit sentence on review-level constraints (database coverage, publication window, language limits if any, and heterogeneity) would strengthen compliance.

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DISCUSSION	23d	Discuss implications for practice, policy, and future research.	Conclusion	Reported	Implications for practice are present.
OTHER INFORMATION - Registration and protocol	24a	Provide review registration information, or state that the review was not registered.	Section 2 plus Supplementary Material S1	Reported	The manuscript clearly states that a review protocol was prepared before screening and that the review was not registered in a public database.
OTHER INFORMATION - Registration and protocol	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Supplementary Material S1	Partial	The protocol is mentioned, but its accessibility is still unclear. If it remained an internal working protocol and is not publicly available, state that explicitly.
OTHER INFORMATION - Registration and protocol	24c	Describe and explain any amendments to registration or protocol information.	Supplementary Material S1 (not yet explicit)	Reported	Supplementary Material S1 explicitly states that no amendments were made to the review protocol after its initial preparation
OTHER INFORMATION - Support	25	Describe sources of financial or non-financial support and the role of funders.	Funding statement	Reported	Financial support is clearly reported. For maximum transparency, you may optionally state that the funder had no role in study selection, synthesis, interpretation, or manuscript preparation, if that is accurate.
OTHER INFORMATION - Competing interests	26	Declare competing interests of review authors.	Conflicts of Interest statement	Reported	Competing interests are clearly declared.
OTHER INFORMATION - Availability of data, code and other materials	27	Report what materials are publicly available and where they can be found.	Data Availability statement	Reported	The Data Availability statement clarifies that no new primary datasets were generated. The cited literature can be accessed through the bibliographic databases used in the review.