INPLASY

Sustainability in Polymeric Membranes: A Systematic Review and Meta-Analysis of Green versus Conventional Solvents on Performance, morphology and Scalability - Protocol

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ADMINISTRATIVE INFORMATION

Support - This review is supported by the PhD School of Geology, Engineering, and Science of Sustainable Earth and Energy Transition (GESET) of the Department of Environmental Engineering (DIAM) at the University of Calabria, Italy.

Review Stage at time of this submission - Data extraction.

Conflicts of interest - None declared.

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Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 9 December 2025 and was last updated on 9 December 2025.

INTRODUCTION

Review question / Objective The objective of this systematic review and meta-analysis is to quantitatively determine whether the use of green or lower-toxicity solvents in polymeric membrane fabrication yields membranes with performance, morphology/structure, sustainability, and scalability outcomes that are comparable to or better than those achieved with conventional hazardous solvents. The review asks whether polymeric membranes fabricated with green solvents perform as well as, or better than, those made with traditional toxic solvents and whether they demonstrate improved environmental sustainability and credible scale-up feasibility across polymers, fabrication routes, and applications.

Rationale Polymeric membranes are central to water treatment, desalination, and gas separations, yet their manufacturing remains highly dependent on hazardous organic solvents such as NMP, DMF, and DMAc, which pose occupational, regulatory, and environmental concerns. In response, the literature increasingly reports green and lower-toxicity alternatives, including PolarClean, dihydrolevoglucosenone (Cyrene), γ-valerolactone (GVL), methyl/ethyl lactate, triethyl phosphate (TEP), dibasic esters (DBEs), and emerging solvent classes such as deep eutectic solvents and ionic liquids. Although individual experimental reports sometimes show promising results, evidence remains fragmented and heterogeneous across polymer systems, fabrication conditions, and target applications, and no prior meta-analysis has consolidated comparative findings. This review will fill that gap by synthesizing head-to-head evidence and applying a materials science appropriate comparator integrity approach and domain-based risk of bias assessment to clarify performance equivalence or improvement, structural and durability implications, reported sustainability indicators, and realistic signals of scalability.

Condition being studied This review addresses an engineering sustainability challenge in polymeric membrane manufacturing: the widespread reliance on hazardous solvents and the feasibility of replacing them with green or lower-toxicity alternatives without compromising membrane performance or scalability. The condition under study is the current solvent-dependent state of polymeric membrane fabrication across major separation applications, and the extent to which safer solvents can mitigate health and environmental risks while maintaining or improving membrane function and manufacturability.

METHODS

Search strategy We will implement a comprehensive and reproducible search strategy across multiple databases using a combination of controlled vocabulary and free text terms relating to green/sustainable solvent concepts and named candidate solvents, polymeric membrane fabrication methods, and performance, morphology, sustainability, and scalability outcomes. The databases (Scopus, Web of Science, PubMed, Google Scholar and research-sharing platforms) will be searched with tailored syntax. Search strategies will be adapted to each platform's indexing rules and fields. No date limits will be applied. The review will be restricted to English-language full texts. We will also conduct backward and forward citation searching and search grey literature sources, including Open Access Theses and Dissertations (OATD), to reduce publication bias.

Participant or population The population of interest is polymeric membranes and their solvent-involving fabrication processes rather than human participants. We will include experimentally fabricated polymeric membranes produced for separation applications such as ultrafiltration, nanofiltration, reverse osmosis, forward osmosis, membrane distillation, and gas separation, provided the study reports extractable quantitative outcomes enabling meaningful comparison of green and conventional solvent systems.

Intervention The intervention of interest is the use of green or lower-toxicity solvents in polymeric membrane fabrication. Eligible studies must use at least one solvent presented or justified as greener or safer than conventional solvents and provide comparative quantitative data against a conventional solvent-based fabrication scenario.

Comparator The comparator is the use of conventional hazardous solvents commonly employed in membrane science, including N-methyl-2-pyrrolidone (NMP), dimethylformamide (DMF), dimethylacetamide (DMAc), tetrahydrofuran (THF), and similar standard solvents. Within-study head-to-head comparisons in which all major fabrication and testing conditions are matched except solvent type will be prioritized.

Study designs to be included We will include original experimental comparative studies, including laboratory and pilot-scale investigations, that fabricate polymeric membranes using green solvents and provide quantitative outcomes enabling comparison with conventional solvent-based membranes. Purely theoretical or modeling studies will be excluded unless they present relevant experimental comparative data.

Eligibility criteria Using the Population, Intervention, Comparator and Outcomes (PICOs) framework, we will include experimental studies involving polymeric membranes fabricated with at least one green solvent and a conventional hazardous solvent comparator, preferably within the same study. Eligible studies must report extractable quantitative outcomes relevant to membrane performance, morphology, mechanical properties, stability, fouling behavior, or sustainability and feasibility indicators such as LCA or TEA when available. We will include only English full texts. We will exclude secondary literature, conference abstracts without full data, editorials, patents, and studies lacking extractable quantitative data or lacking a meaningful comparative basis between green and conventional solvent systems.

Information sources Evidence will be gathered from Scopus, Web of Science, PubMed, ScienceDirect, and Google Scholar, supplemented by grey literature searching including Open Access Theses and Dissertations (OATD), manual backward and forward citation searching, and author contact when necessary to obtain missing statistical information. Search logs and results will be reported in the final manuscript.

Main outcome(s) The primary outcomes are quantitative measures of membrane performance, specifically permeability, permeance, or flux, and rejection or selectivity, including MWCO where reported. These outcomes will be extracted for both green-solvent and conventional-solvent membranes alongside relevant testing conditions to support robust comparisons.

Additional outcome(s) Secondary outcomes will include morphology and structural indicators such as porosity and pore size, mechanical properties, surface characteristics including contact angle, stability and compaction behavior, fouling propensity and cleanability, and any reported sustainability, safety, solvent recovery, techno-economic, or scale-up indicators. These outcomes will allow contextual interpretation of performance results and help assess practical feasibility beyond laboratory demonstrations.

Data management All retrieved records will be imported into Zotero for reference management and deduplication using automated and manual checks. Title and abstract screening and full-text eligibility assessment will be conducted in Rayyan by two independent reviewers with blinded decisions, and discrepancies will be resolved through discussion or a third reviewer. Data extraction will be performed using a standardized Excel form capturing bibliographic details, polymer and solvent systems, fabrication parameters, and all relevant outcome measures. When numerical results are reported only in figures, WebPlotDigitizer will be used with calibration and verification checks. Meta-analyses and statistical computations will be conducted in R using established meta-analysis packages such as metafor and meta, and analytical code will be preserved for reproducibility.

Quality assessment / Risk of bias analysis We will assess the quality of included evidence using a domain-based risk of bias tool adapted for laboratory comparative polymeric membrane studies. The domains will include completeness of fabrication details, solvent identity and characterization, comparator parity, replication and variability reporting, measurement validity and clarity of test conditions, selective reporting, and funding or competing interests. Comparator parity, replication/variability, and measurement validity will be treated as critical domains. Each domain will be rated as low risk, some concerns, high risk, or not reported by two independent reviewers, with disagreements resolved by consensus or a third reviewer. Risk of bias judgements will inform sensitivity analyses and confidence in conclusions.

Strategy of data synthesis We will combine quantitative meta-analysis with structured narrative synthesis. When at least three sufficiently comparable comparisons are available, we will perform random-effects meta-analyses. For continuous outcomes we will use weighted mean difference when units and test definitions are consistent, standardized mean difference when scales or units differ, and a pre-specified log response ratio approach for flux or permeance when unit heterogeneity is substantial. To manage confounding common in materials experiments, the primary unit of analysis will be the within-study green versus conventional comparison pair. Comparator strictness tiers will be applied, with Tier 1 representing solvent-only changes under matched fabrication and testing conditions and prioritized for the main meta-analysis, Tier 2 representing minor justified co-variations included in sensitivity analyses or meta-regression, and Tier 3 representing multi-variable confounding restricted to narrative synthesis. Heterogeneity will be assessed using I^2 and explored through subgroup analyses and meta-regression where data permit. When pooling is not appropriate, findings will be synthesized narratively and organized by polymer type, solvent class, fabrication method, and application.

Subgroup analysis We will explore potential effect modification by polymer type, green solvent class, fabrication method including NIPS, VIPS, TIPS and electrospinning, application category such as UF, NF, RO, FO, MD, and gas separation, and key process moderators where reported sufficiently, including polymer concentration, coagulation bath composition, and post-treatment conditions.

Sensitivity analysis We will test robustness by restricting analyses to Tier 1 comparisons, excluding studies with high risk in critical bias domains, comparing fixed-effect and random-effects models, and conducting influence analyses where appropriate. Additional condition-matched sensitivity analyses may be undertaken if adequate data exist for tightly controlled subsets.

Language restriction We will include only studies for which an English full text is available.

Country(ies) involved This review is being carried out in Italy, with all authors affiliated with institutions in Italy. The review will synthesize global evidence irrespective of the geographic origin of included studies.

Other relevant information This protocol is prepared in alignment with PRISMA 2020 standards to ensure rigorous and transparent reporting. Any methodological deviations from this protocol will be documented and justified in the final manuscript. The authors intend to share data extraction materials and analysis code in an appropriate open repository where feasible to enhance reproducibility and facilitate future evidence syntheses.

Keywords Green solvents; polymeric membranes; phase inversion; NIPS; VIPS; TIPS; electrospinning; sustainability; life cycle assessment; techno-economic analysis; scalability.

Dissemination plans The findings will be disseminated through peer-reviewed publication, with a preprint considered where appropriate, and through presentations at conferences focused on membrane technology, green chemistry, and sustainable materials. The underlying extracted dataset and meta-analysis code will be shared publicly where feasible to enable verification, reuse, and integration into future research and policy discussions.

Contributions of each author

Author 1 - Dinaol Bedada Dibaba - Conceptualized the study and formulated the research question. Developed the methodology and search strategy. Performed the literature search and initial screening. Will lead data extraction, carry out the meta-analysis, and draft the manuscript.
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Author 2 - Sergio SANTORO - Contributed to the study conception and design. Provided supervision and expert guidance. Will assist in study selection and validation of extracted data. Reviewed and edited the protocol for important intellectual content.
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Author 3 - Pietro Argurio - Advised on the methodology, especially the experimental aspects of membrane fabrication to ensure relevant data are captured. Provided key resources and expertise. Will take part in resolving any discrepancies during data extraction and will review the analysis and manuscript for accuracy.
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Author 4 - Efrem Curcio - Offered refinement of the review methodology and ensured the completeness of the protocol. Provided oversight as the senior author, including securing necessary resources. Will supervise the project's progress, verify the data analysis, and assist in the editing and final approval of the manuscript.
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