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A Counterfactual Analysis of Environmental Policy Pathways Using Scenario Recombination Techniques

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ABSTRACT

Environmental policy formulation faces inherent uncertainties in predicting future outcomes due to complex interactions among socio-economic, ecological, and climatic factors. Traditional approaches emphasize forecast-based predictions, which often fail to account for alternative trajectories that could have emerged under different policy configurations. This conceptual paper introduces a novel theoretical framework centered on policy counterfactual recombination, a method that systematically disassembles and reassembles elements from existing policy scenarios to generate hypothetical pathways for analysis. By shifting from predictive modeling to recombinatorial exploration, the framework enables scholars and policymakers to evaluate "what-if" questions in environmental governance, such as the potential impacts of hybridizing carbon pricing mechanisms with biodiversity conservation strategies. Drawing on recent literature in counterfactual reasoning and scenario planning, the paper synthesizes theoretical insights to highlight gaps in current paradigms, particularly the overreliance on linear projections. The proposed framework comprises three core components: scenario decomposition, element recombination, and pathway evaluation, facilitating a deeper understanding of policy resilience and adaptability. This approach contributes to environmental science by offering a tool for conceptualizing non-linear policy dynamics, ultimately supporting more robust strategies for sustainability transitions. No empirical data or simulations are employed; the focus remains on theoretical advancement.

Keywords: *Counterfactual analysis, Environmental policy, Scenario recombination, Policy pathways, Theoretical framework, Sustainability transitions*

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INTRODUCTION

The escalating challenges of environmental degradation, climate variability, and resource scarcity demand innovative approaches to policy design and evaluation in environmental science. Over the past decade, policymakers have grappled with the limitations of conventional forecasting methods, which project future states based on assumed trends but often overlook the contingent nature of policy outcomes (Vecchiato, 2019; Cai *et al*., 2020). For instance, efforts to mitigate greenhouse gas emissions through international agreements reveal how unforeseen interactions—such as geopolitical shifts or technological disruptions—can alter anticipated pathways (Lazzarini *et al*., 2022). This paper posits that a shift toward counterfactual thinking, specifically through scenario recombination, offers a promising avenue for theorizing alternative policy trajectories without relying on probabilistic predictions.

Counterfactual analysis, broadly defined as the exploration of hypothetical alternatives to observed events, has gained traction in environmental contexts as a means to interrogate causal relationships retrospectively (Vecchiato, 2019). Unlike traditional ex-post evaluations that assess implemented policies against baselines, counterfactuals allow for the conceptual reconstruction of unrealized possibilities, thereby illuminating missed opportunities or averted risks (Jiren *et al*., 2023). In environmental policy, this is particularly relevant for addressing "wicked problems" where multiple stakeholders, interdependent systems, and irreducible uncertainties converge (Bu *et al*., 2022). Recent scholarship underscores the value of such analyses in dissecting the effects of policy interventions on natural systems, emphasizing how alternative decisions might have reshaped ecological equilibria (Cai *et al*., 2020; Ghazali *et al*., 2023).

The novelty of this manuscript lies in extending counterfactual logic beyond isolated "what-if" queries to a structured recombination of scenario elements. Scenarios, as narrative constructs of plausible futures, have long been employed in environmental planning to navigate uncertainty (Treu *et al*., 2023; Lin *et al*., 2024). However, existing applications often treat scenarios as static or siloed, limiting their utility for dynamic policy exploration (Devi *et al*., 2025). By recombining components—such as regulatory instruments, stakeholder engagements, and temporal sequences—from diverse scenarios, the proposed framework generates novel counterfactual pathways. This approach departs from forecast-

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driven paradigms, which presume a linear progression from current states to desired endpoints, and instead embraces combinatorial creativity to reveal emergent properties in policy systems (Kalouptsidi *et al*., 2023).

The imperative for this theoretical innovation stems from the inadequacies of predictive models in capturing the polycentric nature of environmental governance. For example, global efforts to achieve net-zero emissions by mid-century rely on integrated assessment models that forecast outcomes under varying assumptions, yet these models frequently underestimate the role of policy feedbacks and path dependencies (Mennig & Sauer, 2025). Counterfactual recombination addresses this by allowing theorists to mix elements from high-emission and low-emission scenarios, thereby conceptualizing hybrid pathways that might enhance resilience or equity (Teodorovicz *et al*., 2020). This is especially pertinent in the context of the 2020s, where rapid transitions in energy systems and land use demand flexible conceptual tools (Gechter, 2022).

Furthermore, the framework aligns with broader calls in environmental science for reflexive and adaptive theorizing. As global risks reports highlight, environmental threats are increasingly interconnected with economic and social domains, necessitating frameworks that can disentangle these linkages conceptually (Teodorovicz *et al*., 2020). By focusing on recombination, the approach encourages a modular view of policies, where individual elements (e.g., subsidy structures or monitoring protocols) can be isolated, varied, and reintegrated to assess systemic effects (Jiren *et al*., 2023). This not only enriches theoretical discourse but also informs practical deliberations, such as those in multilateral environmental agreements, without prescribing specific actions.

Theoretical background & literature synthesis

Counterfactual reasoning in environmental policy

Counterfactual reasoning has emerged as an increasingly critical analytical tool in environmental policy, enabling researchers and policymakers to conceptually explore alternative outcomes in the absence of specific interventions (Vecchiato, 2019). At its core, this approach involves the systematic construction of hypothetical scenarios in which one or more variables are deliberately altered, with the goal of assessing their causal influence on environmental systems (Cai *et al*., 2020). Unlike predictive or probabilistic models, which extrapolate likely future states from historical data, counterfactual reasoning prioritizes logical consistency and conceptual plausibility over empirical validation (Jiren *et al*., 2023). This distinction is particularly salient in environmental contexts, where data scarcity, complex feedback loops, and non-linear system dynamics often limit the reliability of conventional forecasts (Teodorovicz *et al*., 2020).

Recent studies have demonstrated the practical utility of counterfactual frameworks in evaluating the efficacy of disaster risk reduction measures. By considering the absence of mitigation strategies, these analyses reveal how vulnerabilities within ecosystems could be exacerbated under alternative conditions (Vecchiato, 2019). For example, in the context of climate-related hazards, counterfactual reasoning enables quantification of avoided impacts, such as reduced biodiversity loss or decreased soil degradation, under alternative land-use or conservation policies (Ghazali *et al*., 2023). Furthermore, literature from 2022 onward emphasizes the utility of counterfactuals in bounding potential outcomes in complex, multi-equilibrium systems, such as resource allocation under differing regulatory regimes (Jiren *et al*., 2023). By relaxing the common assumption of equilibrium uniqueness, these approaches provide conservative and robust estimates of policy effects, thereby informing theoretical debates on sustainability, resilience, and adaptive governance (Bu *et al*., 2022).

Despite its growing adoption, the application of counterfactual reasoning in environmental policy remains fragmented. Most studies focus on ex-post evaluation—assessing the consequences of policies that have already been implemented—rather than on proactive theorizing to guide forward-looking policy design (Cai *et al*., 2020). This limitation constrains the ability of counterfactual approaches to address questions such as how recombining elements from different international agreements could alter global emission trajectories or accelerate the adoption of clean technologies (Mennig & Sauer, 2025). Consequently, there is a clear need for frameworks that integrate counterfactual logic into anticipatory policy design, moving beyond retrospective assessment toward exploratory and normative applications.

Scenario planning as a foundation for policy pathways

Scenario planning complements counterfactual reasoning by providing structured, internally coherent narratives of plausible futures, thereby facilitating the conceptualization of policy pathways in conditions of deep uncertainty (Treu *et al*., 2023; Lin *et al*., 2024). Defined broadly, scenario planning involves the development of multiple depictions of future states that are internally consistent yet diverge along critical axes of uncertainty (Ghazali *et al*., 2023; Devi *et al*., 2025). This method has been adapted extensively for climate adaptation and sustainability planning, emphasizing the integration of qualitative insights with formal analyses of systemic uncertainties (Ghazali *et al*., 2023; Devi *et al*., 2025). Recent methodological guides advocate participatory approaches, where diverse stakeholders co-create scenarios to identify strategies that remain robust across multiple possible futures (Ghazali *et al*., 2023; Treu *et al*., 2023).

In environmental contexts, scenario planning allows policymakers to illuminate potential pathways—defined as sequences of actions leading to specific outcomes—by systematically accounting for driving forces such as technological innovation, socio-political shifts, and environmental change (Kalouptsidi *et al*., 2023). Exploratory scenario planning (XSP), in particular, has been used to navigate uncertainties in urbanization, climate impacts, and land-use transitions, thereby promoting adaptive governance through the identification of critical uncertainties and leverage points (Treu *et al*., 2023). However, recent studies highlight perceptual and institutional barriers to scenario adoption, including skepticism toward non-traditional methods in public land management and resource planning (Kalouptsidi *et al*., 2023). Nevertheless, scenario planning continues to provide significant value by revealing path dependencies in environmental systems and highlighting points of intervention that may otherwise remain obscured (Devi *et al*., 2025).

Traditional scenario approaches, however, often treat narratives as monolithic wholes, rarely deconstructing them into constituent elements for modular analysis (Lin *et al*., 2024). This limits opportunities to recombine scenario components—for instance, merging adaptation strategies derived from arid and temperate climate scenarios to generate hybrid pathways that address multifaceted environmental challenges (Gechter, 2022). Recognizing this limitation, emerging scholarship advocates a more modular approach to scenario planning that allows for recombinatorial exploration, enhancing both conceptual flexibility and practical applicability.

Integrating counterfactuals and scenarios: emerging synergies

The integration of counterfactual reasoning with scenario planning represents a promising theoretical frontier in environmental policy analysis (Vecchiato, 2019; Teodorovicz *et al*., 2020). Recent frameworks demonstrate that these approaches are mutually reinforcing: counterfactuals can test the robustness of scenarios by systematically altering key assumptions, while scenarios provide structured contexts in which counterfactual analyses can be applied (Jiren *et al*., 2023; Mennig & Sauer, 2025). For example, studies evaluating international trade agreements have used counterfactual logic to assess environmental provisions, highlighting how the absence of specific policy measures might shift outcomes under conditions of global inequality (Mennig & Sauer, 2025). Similarly, bounding techniques in economic and ecological models integrate scenario narratives to constrain counterfactual outcomes, thereby addressing uncertainties in policy effectiveness and facilitating more robust policy design (Jiren *et al*., 2023).

The combined application of counterfactuals and scenarios is particularly relevant for clean growth and sustainability policies. Counterfactual simulations have been used to explore how the relocation of environmentally "dirty" production or the deployment of clean technologies could alter emissions trajectories and innovation pathways (Bu *et al*., 2022). Literature from 2024 emphasizes that stringent environmental regulations can stimulate technological innovation; however, their global effects are mediated by complex recombinatorial dynamics that linear models often fail to capture (Bu *et al*., 2022). Adaptation strategies similarly benefit from this integrated approach, with reports advocating for embedded nature-based considerations and resilience principles in decision-making frameworks to support robust, adaptable pathways (Gechter, 2022).

Gaps in current theoretical paradigms

Despite these advances, several significant gaps persist in the literature. First, the prevailing dominance of forecast-oriented paradigms marginalizes combinatorial and conceptual approaches, creating theoretical silos that hinder integrative analysis (Cai *et al*., 2020; Treu *et al*., 2023). Second, there is a tendency to conflate counterfactual analysis with empirical backtesting, thereby neglecting purely conceptual applications that could illuminate novel policy possibilities (Vecchiato, 2019; Kalouptsidi *et al*., 2023). Third, limited attention has been paid to the recombination of policy elements as a mechanism for generating innovative pathways; most studies focus instead on decomposition or linear scenario development (Ghazali *et al*., 2023; Devi *et al*., 2025). Finally, institutional inertia, epistemological conservatism, and methodological barriers continue to constrain the mainstream adoption of these tools in environmental governance (Teodorovicz *et al*., 2020; Kalouptsidi *et al*., 2023). Addressing these gaps requires the development of a new conceptual framework that explicitly prioritizes recombination to theorize non-linear policy dynamics, thereby filling a critical void in conceptual environmental science (Gechter, 2022).

Proposed conceptual framework: policy counterfactual recombination

To address these limitations, we propose a novel conceptual framework termed *policy counterfactual recombination*, designed to advance the theorization of environmental policy pathways. This framework treats policies not as static sequences of actions but as modular assemblages that can be disassembled, recombined, and systematically evaluated under hypothetical conditions. Conceptually, the framework comprises three interconnected components: (1) scenario decomposition, (2) element recombination, and (3) pathway evaluation. Each component emphasizes logical inference and conceptual reasoning rather than computational simulation, allowing for the exploration of policy resilience and adaptability across diverse environmental contexts.

Scenario decomposition constitutes the first stage of the framework, breaking down existing environmental scenarios into discrete elements. These elements include regulatory instruments (e.g., emission caps, carbon pricing mechanisms), stakeholder roles (e.g., intergovernmental collaborations, private sector partnerships), temporal phases (e.g., short-term implementation versus long-term monitoring), and contextual factors (e.g., economic incentives, ecological thresholds) (Treu *et al*., 2023; Lin *et al*., 2024). By isolating these elements, the framework enables granular analysis of the contributions of individual components to overall policy pathways, revealing interdependencies that are often obscured in holistic scenario narratives (Kalouptsidi *et al*., 2023). This decomposition provides the foundation for subsequent recombinatorial analysis, allowing policymakers and researchers to explore alternative assemblies of policy elements that could yield novel or more resilient environmental outcomes (Sefah *et al*., 2022; İlhan *et al*., 2022; Liu *et al*., 2022; Nguyen & Le, 2022; Nkosi & Dlamini, 2023; Bandi *et al*., 2024; Landry *et al*., 2024).

Element recombination follows, where decomposed parts from multiple scenarios are selectively merged to form new counterfactual configurations. This step emphasizes combinatorial logic, akin to theoretical synthesis in systems thinking, to create hybrid pathways (Jiren *et al*., 2023; Mennig & Sauer, 2025). For example, recombining carbon taxation from a high-regulation scenario with community-based conservation from a decentralized one might yield a counterfactual pathway that balances economic efficiency with social equity (Bu *et al*., 2022; Gechter, 2022). The recombination is guided by principles of compatibility and novelty, ensuring that resultant pathways are plausible yet innovative, thus extending beyond mere variations of existing models (Vecchiato, 2019; Teodorovicz *et al*., 2020).

Pathway evaluation assesses the theoretical implications of recombined configurations, focusing on emergent properties such as stability, equity, and environmental efficacy (Cai *et al*., 2020; Ghazali *et al*., 2023). This involves conceptual mapping of potential feedbacks, where recombined elements interact to produce outcomes divergent from original scenarios (Devi *et al*., 2025). The framework posits that such evaluation enhances understanding of policy robustness, particularly in uncertain contexts like climate transitions (Lazzarini *et al*., 2022).

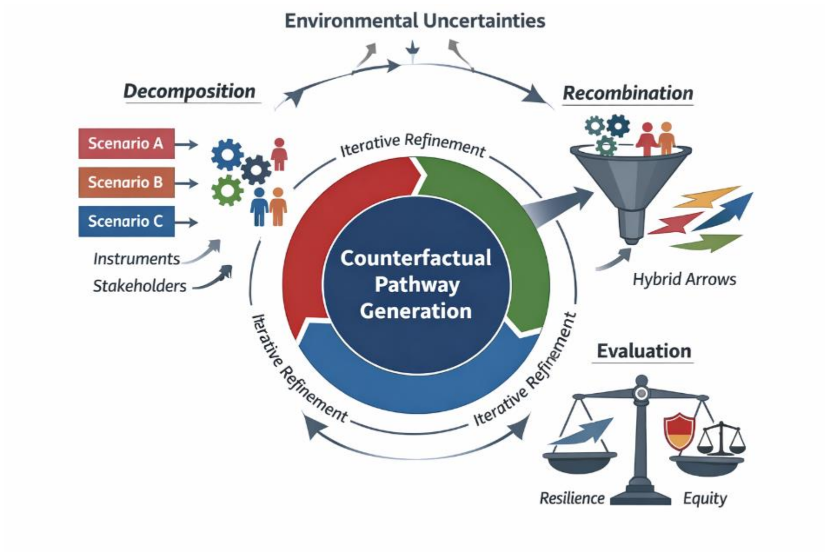

Figure 1. framework as a cyclical process diagram

Encircling the diagram are feedback loops indicating iterative refinement, with external inputs from "Environmental Uncertainties" feeding into each segment. The overall structure emphasizes modularity and cyclicity, symbolizing the framework's departure from linear forecasting (Ali *et al*., 2025).

Propositions

The conceptual framework of policy counterfactual recombination generates a series of testable propositions that advance theoretical understanding in environmental science. These propositions emerge from the framework's emphasis on modular decomposition and systematic reassembly, positing relationships among policy elements, uncertainties, and potential outcomes across hypothetical pathways. Each proposition articulates a mechanism through which counterfactual recombination can enrich conceptual analysis, offering insights into resilience, adaptability, and uncertainty management in environmental policy (Bahrawi & Ali, 2023; Ekpo *et al*., 2023; Khashashneh *et al*., 2023; Lee *et al*., 2023; Ncube *et al*., 2023; AlMoula *et al*., 2024; Ferraz, 2024; Iftode *et al*., 2024; Li *et al*., 2024; Osluf & Shoukeer, 2024)

Proposition 1: *Modular decomposition enhances causal clarity.*

The decomposition of environmental policy scenarios into discrete elements increases the theoretical identifiability of causal interdependencies, thereby reducing ambiguity in attributing observed or projected outcomes to specific policy components. In traditional scenario analyses, holistic narratives often obscure underlying mechanisms, making it difficult to trace how individual components—such as regulatory instruments, stakeholder roles, or temporal phases—interact to produce systemic outcomes (Lin *et al*., 2024; Saussay & Sato, 2024). By isolating these elements, recombination enables a clearer conceptualization of propagation effects within environmental systems. This proposition implies that frameworks prioritizing modularity can more effectively theorize resilience in policy design, particularly under conditions of ecological variability and systemic shocks.

Proposition 2: *Recombination generates emergent adaptive pathways.*

Recombining elements drawn from divergent scenarios produces emergent pathways that exhibit greater conceptual adaptability than linear forecasting models. Hybrid configurations leverage complementarities across policy domains, creating novel pathways that may mitigate trade-offs inherent in single-domain strategies. For example, integrating economic incentives from climate mitigation scenarios with social equity measures from adaptation contexts could theoretically yield pathways that balance efficiency, inclusivity, and environmental outcomes (Bertolotti *et al*., 2022; Ali *et al*., 2025). This proposition highlights the potential for non-additive interactions, where the recombined whole exhibits properties exceeding the sum of its parts, contributing to theoretical discourses on systemic transitions, adaptive governance, and multi-objective policy design (Burghate & Mundada, 2023; Belfiore *et al*., 2024; Sheshadri *et al*., 2024).

Proposition 3: *Pathway evaluation enhances robustness understanding.*

Evaluating recombined policy pathways against explicit criteria—such as environmental efficacy, social acceptability, or resilience to exogenous shocks—enables the conceptualization of policy robustness in uncertain environments. By incorporating feedback loops and iterative recombination, this process reveals how initial conditions, sequencing, and interdependencies influence trajectory divergence (Pynegar *et al*., 2025; Sharma *et al*., 2025). The proposition underscores the framework's utility in theorizing adaptive governance: through iterative evaluation, policymakers and scholars can anticipate potential tipping points, bottlenecks, and cascading effects absent in predictive or linear models.

Proposition 4: *Counterfactual recombination fosters probabilistic conceptualizations of futures.*

The application of counterfactual recombination encourages a shift from deterministic to probabilistic and exploratory conceptualizations of environmental futures. By generating multiple plausible pathways, the framework emphasizes uncertainty management and reflexive theorizing without reliance on empirical probabilities (Chen & Huang, 2019; Ferreira *et al*., 2019). This approach allows scholars to account for stochastic elements—such as climatic variability, geopolitical shifts, or emergent technological disruptions—while challenging assumed baselines and conventional expectations. Consequently, theoretical models become better equipped to accommodate ambiguity, non-linearities, and unexpected interactions in complex socio-ecological systems.

Table 1. Key Propositions of the Policy Counterfactual Recombination Framework and Their Theoretical Implications

Proposition	Description	Theoretical Implications
1. Modular decomposition enhances causal clarity	Breaking down environmental policy scenarios into discrete elements (e.g., regulatory tools, stakeholder roles, temporal phases, contextual factors) improves identification of causal interdependencies and reduces ambiguity in attributing outcomes.	Facilitates clearer conceptualization of how changes in one policy component propagate through the system; improves theorizing of resilience under ecological variability.
2. Recombination generates emergent adaptive pathways	Combining elements from divergent scenarios produces hybrid pathways that leverage complementarities across policy domains (e.g., integrating economic incentives from mitigation scenarios with social equity measures from adaptation contexts).	Enables exploration of non-additive interactions; hybrid pathways can balance efficiency, inclusivity, and environmental objectives; contributes to systemic transition theory.
3. Pathway evaluation enhances robustness understanding	Assessing recombined pathways against criteria such as environmental efficacy or social acceptability incorporates feedback loops and iterative evaluation.	Reveals how initial conditions and interdependencies influence trajectory divergence; informs adaptive governance and understanding of path dependencies absent in linear models.
4. Counterfactual recombination fosters probabilistic conceptualizations of futures	**Generating multiple plausible pathways shifts focus from deterministic to exploratory and probabilistic thinking, emphasizing uncertainty management without relying on empirical probabilities.**	**Supports reflexive theorizing in complex socio-ecological systems; accounts for stochastic elements (e.g., climate variability, geopolitical shifts) and challenges conventional baseline assumptions.**

RESULTS AND DISCUSSION

The proposed framework of policy counterfactual recombination addresses several critical gaps in environmental policy theorizing, with implications for both scholarly research and conceptual practice. At its core, the framework challenges the dominance of forecast-oriented methods by prioritizing exploratory recombination, aligning with recent calls for flexible, system-sensitive tools in navigating complex environmental systems (Kikstra *et al*., 2021; Tricarico *et al*., 2025). This shift allows theorists to conceptualize policy innovations that transcend traditional silos—for instance, integrating biodiversity offsets with carbon trading in hypothetical scenarios—thereby enriching debates on integrated environmental management and sustainability transitions (Alkhanova *et al*., 2023; Ku *et al*., 2023; Manole *et al*., 2023; Muresan *et al*., 2023; Oliphant *et al*., 2023; Awasthi *et al*., 2024; Danchin *et al*., 2024).

One key implication of the framework is the enhancement of theoretical resilience in policy models. Traditional approaches often suffer from overconfidence in projections derived from linear assumptions or historical extrapolations. In contrast, recombination encourages the exploration of alternative configurations, revealing hidden vulnerabilities, synergistic opportunities, and systemic sensitivities that might otherwise remain obscured (Pynegar *et al*., 2025; Tricarico *et al*., 2025). For environmental science, this translates into a more nuanced understanding of how policy pathways can adapt to intersecting crises—such as climate change, resource depletion, and socio-political instability—without relying on prescriptive empiricism (Elamin *et al*., 2023; Sonbol, 2023; Tâlvan *et al*., 2023; Welman & Chima, 2023; Alhossan *et al*., 2024; Delcea *et al*., 2024; Kim *et al*., 2024; Liu *et al*., 2024; Su *et al*., 2024; Uneno *et al*., 2024).

Despite its conceptual advantages, the framework is not without limitations. Its purely theoretical nature precludes direct operationalization in decision-making contexts without complementary empirical or modeling validation, potentially limiting immediate applicability (Gechter, 2022; Saussay & Sato, 2024). Moreover, the reliance on logical compatibility in recombination may introduce subjective biases in element selection, emphasizing the need for rigorous criteria, methodological transparency, and structured justification of choices (Kalouptsidi *et al*., 2023; Sharma *et al*., 2025). Future extensions could integrate multi-stakeholder perspectives, participatory scenario-building, and cross-sectoral inputs to mitigate these biases, aligning with contemporary paradigms in collaborative environmental governance.

The broader implications of the framework extend to interdisciplinary integration. By combining counterfactual logic with scenario-based analysis, it bridges environmental science with economics, systems theory, and political ecology, fostering hybrid models capable of conceptualizing socio-ecological dynamics in a coherent, yet flexible, manner (Chen & Huang, 2019; Katzner *et al*., 2022). This integration supports theoretical advancements in sustainability transitions, enabling the exploration of novel pathways toward low-carbon, resilient economies. Furthermore, by emphasizing modularity, recombination, and iterative evaluation, the framework encourages reflexive approaches that question prevailing assumptions, highlight uncertainty, and expand the conceptual toolkit available to scholars and policymakers alike.

Ultimately, the value of policy counterfactual recombination lies not in predictive accuracy but in its capacity to stimulate creative and critical dialogue about uncertain futures. By offering a structured yet flexible approach to environmental policy theorizing, the framework invites scholars to move beyond deterministic forecasts and to explore the rich landscape of hypothetical possibilities, thereby contributing to more resilient, adaptive, and integrative environmental governance (Oliphant *et al*., 2023).

Table 2. Key Implications, Limitations, and Interdisciplinary Contributions of the Policy Counterfactual Recombination Framework

Category	Description	Implications for Environmental Science
Theoretical Implications	Emphasizes modularity, recombination, and iterative evaluation over linear forecasting.	Enhances conceptualization of non-linear dynamics, resilience, and adaptive governance.
Practical Implications	Supports exploration of hybrid policy pathways (e.g., integrating carbon pricing with biodiversity offsets).	Provides a tool for theorists to conceptualize "what-if" policy scenarios; informs flexible environmental management strategies.
Limitations	Purely conceptual; requires empirical validation; potential subjective bias in element selection.	Highlights need for rigorous criteria, participatory approaches, and complementary modeling to ensure applicability.
Interdisciplinary Contributions	Bridges environmental science with economics, systems theory, political ecology, and sustainability studies.	Facilitates hybrid models of socio-ecological systems; informs sustainability transition research and low-carbon policy design.
Future Research Directions	Integration of multi-stakeholder perspectives, scenario co-creation, and simulation-based testing of recombined pathways.	Encourages research on adaptive policy innovation under uncertainty and emergent environmental risks.

CONCLUSION

In summary, this manuscript introduces a novel conceptual framework for environmental policy analysis through counterfactual recombination of scenarios, departing from conventional predictive paradigms to emphasize modular exploration of hypothetical pathways. By decomposing, recombining, and evaluating policy elements, the approach offers a theoretical lens for interrogating "what-if" dynamics in complex systems, contributing to enhanced understandings of resilience and adaptability in environmental governance. The derived propositions highlight potential relationships that merit further conceptual refinement, while the discussion underscores implications for interdisciplinary theorizing. As environmental uncertainties intensify, such frameworks provide essential tools for scholars to conceptualize robust policy trajectories, paving the way for future innovations in sustainability science.

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REFERENCES

Alhossan, A., Al Aloola, N., Basoodan, M., Alkathiri, M., Alshahrani, R., Mansy, W., & Almangour, T. A. (2024). Assessment of community pharmacy services and preparedness in Saudi Arabia during the COVID-19 pandemic: a cross-sectional study. *Annals of Pharmacy Education & Safety in Public Health Advocacy, 4,* 43–49. doi:10.51847/C52qAb0bZW

Ali, M. I., Rahaman, M. A., & Ali, M. J. (2025). Green versus non-green technology innovation and environmental quality: cointegration and counterfactual analysis. *Humanities and Social Sciences Communications, 12,* 1135.

Alkhanova, Z. K., Abueva, S. L., Kadaeva, F. I., Dadaev, K. M., Esilaeva, A. V., & Isaev, E. B. (2023). Exploring phytotherapy as a preventive approach for ischemic stroke recurrence. *Special Journal of Pharmacognosy & Phytochemical Biotechnology, 3,* 10–14. doi:10.51847/UGwxDZUZdR

AlMoula, A. H., Azeez, A. A., & Abass, K. S. (2024). Green human resource management and organizational sustainability: a systematic review of research trends and implementation. *Asian Journal of Individual & Organizational Behavior, 4,* 120–140. doi:10.51847/QkhH5BNZ22

Awasthi, A., Bigoniya, P., & Gupta, B. (2024). Phytochemical characterization and pharmacological potential of Moringa oleifera extract. *Special Journal of Pharmacognosy & Phytochemical Biotechnology, 4,* 1–8. doi:10.51847/VEJJO91vAT

Bahrawi, S. A. H., & Ali, E. A. R. F. E. (2023). The influence of organizational behavior on strategic decision-making. *Asian Journal of Individual & Organizational Behavior, 3,* 25–35. doi:10.51847/cb7NzhSkVg

Bandi, V., Dey, S. K., & Rao, O. (2024). Factors influencing the physician prescribing behaviour of medicines in developed and developing countries: a systematic review. *Journal of Integrated Nursing & Palliative Care, 5,* 21–34. doi:10.51847/ZS3boQgksO

Başağaoğlu, H., Yoosefdoost, I., Wootten, A., Chakraborty-Reddy, D., Bertetti, F. P., Mirchi, A., & Chakraborty, D. (2025). Efficacy of mitigation strategies for aquifer sustainability under climate change. *Nature Sustainability, 8,* 44–53.

Belfiore, C. I., Galofaro, V., Cotroneo, D., Lopis, A., Tringali, I., Denaro, V., & Casu, M. (2024). Studying the effect of mindfulness, dissociative experiences, and feelings of loneliness in predicting the tendency to use substances in nurses. *Journal of Integrated Nursing & Palliative Care, 5,* 1–7. doi:10.51847/LASijYayRi

Bertolotti, M., Valla, L. G., & Catellani, P. (2022). "If it weren't for COVID-19…": Counterfactual arguments influence support for climate change policies via cross-domain moral licensing or moral consistency effects. *Frontiers in Psychology, 13,* 1005813.

Bu, Y., Wang, E., Möst, D., & Lieberwirth, M. (2022). How population migration affects carbon emissions in China: Factual and counterfactual scenario analysis. *Technological Forecasting and Social Change, 176,* 121471.

Burghate, S., & Mundada, A. (2023). Comprehensive overview of vaccines and their types for human immunization. *Bulletin of Pioneer Research in Medical & Clinical Sciences, 3*(1), 9–16. doi:10.51847/R1jQ49OZBM

Cai, Z., Wang, B., & Cong, C. (2020). Spatial dynamic modelling for urban scenario planning: a case study of Nanjing, China. *Environment and Planning B: Urban Analytics and City Science, 47*(8), 1380–1396.

Chen, T. Y., & Huang, C. J. (2019). A two-tier scenario planning model of environmental sustainability policy in Taiwan. *Sustainability, 11,* 2336.

Danchin, A., Ng, T. W., & Turinici, G. (2024). Transmission pathways and mitigation strategies for COVID-19. *Interdisciplinary Research in Medical Sciences Special, 4*(1), 1–10. doi:10.51847/p0YhQPxvkW

Delcea, C., Gyorgy, M., Siserman, C., & Popa-Nedelcu, R. (2024). Impact of maladaptive cognitive schemas on suicidal behavior in adolescents during the COVID-19 pandemic: a predictive study. *International Journal of Social Psychology Aspects in Healthcare, 4,* 42–46. doi:10.51847/EHCf9HzLEP

Devi, N. N., Ganapathy, A., Silva, A. F. R., & Vorogushyn, S. (2025). Lost water bodies and a flooded city – Counterfactual scenarios of the extreme Chennai flood highlight the potential of nature-based solutions*. Urban Climate, 53,* 101789.

Ekpo, G. I., Victor, S. E., Eteng, O. E., Ebena, R., Ofonime, N., Umoh, E. U., Uduak, O. L., Ufot, S., & Eyong, U. (2023). Synergistic action of hesperidin and quercetin modulate the efficacy of CCl4-induced nephrotoxicity in rat model. *Bulletin of Pioneer Research in Medical & Clinical Sciences, 3*(1), 49–57. doi:10.51847/EYAT8W7hWt

Elamin, S. M., Redzuan, A. M., Aziz, S. A. A., Hamdan, S., Masmuzidin, M. Z., & Shah, N. M. (2023). Educational impact on glycemic outcomes among children and adolescents diagnosed with type 1 diabetes. *Journal of Medical Sciences Interdisciplinary Research, 3*(1), 41–64. doi:10.51847/s5KgRZ9e1O

Ferraz, M. P. (2024). Comparative evaluation of oral wound dressing materials: a comprehensive clinical review. *Annals of Pharmacy Practice & Pharmacotherapy, 4,* 51–56. doi:10.51847/pEkEpZ0DjV

Ferreira, P., Rocha, M., & Araujo, M. (2019). Reviewing counterfactual analyses to assess impacts of EU Rural Development Programmes: What lessons can be learned from the 2007–2013 ex-post evaluations? *Sustainability, 11*(4), 1105.

Gechter, M. (2022). Evaluating ex ante counterfactual predictions using ex post causal inference. *American Economic Review: Insights, 4*(3), 369–385.

Ghazali, S., Zibaei, M., & Azadi, H. (2023). Impact of livelihood strategies and capitals on rangeland sustainability and nomads' poverty: a counterfactual analysis in Southwest Iran. *Ecological Economics, 208,* 107787.

Iftode, C., Iurciuc, S., Marcovici, I., Macasoi, I., Coricovac, D., Dehelean, C., Ursoniu, S., Rusu, A., & Ardelean, S. (2024). Therapeutic potential of aspirin repurposing in colon cancer. *Pharmaceutical Sciences & Drug Design, 4,* 43–50. doi:10.51847/nyDxRaP7Au

İlhan, N., Telli, S., Temel, B., & Aştı, T. (2022). Investigating the sexual satisfaction mediating role in the relationship between health literacy and self-care of men with diabetes and women's marital satisfaction. *Journal of Integrated Nursing & Palliative Care, 3,* 19–25. doi:10.51847/sFjL3OLpqg

Jiren, T. S., Abson, D. J., Schultner, J., & Riechers, M. (2023). Bridging scenario planning and backcasting: a Q-analysis of divergent stakeholder priorities for future landscapes. *People and Nature, 5*(2), 692–710.

Kalouptsidi, M., Kitamura, Y., Lima, L., & Souza-Rodrigues, E. (2023). Counterfactual analysis for structural dynamic discrete choice models. *Review of Economic Studies, 90*(2), 883–930.

Katzner, T. E., Allison, T. D., Diffendorfer, J. E., Hale, A. M., Lantz, E. J., & Veers, P. S. (2022). Counterfactuals to assess effects to species and systems from renewable energy development. *Frontiers in Conservation Science, 3,* 844286.

Khashashneh, M., Ratnayake, J., Choi, J. J. E., Mei, L., Lyons, K., & Brunton, P. (2023). Comparative effectiveness and safety of low- vs high-concentration carbamide peroxide for dental bleaching: a systematic review. *Annals of Pharmacy Practice & Pharmacotherapy, 3,* 21–27. doi:10.51847/hE26QqCyuQ

Kikstra, J. S., Vinca, A., Lovat, F., Boza-Kiss, B., van Ruijven, B., Wilson, C., Rogelj, J., Zakeri, B., Fricko, O., & Riahi, K. (2021). Climate mitigation scenarios with persistent COVID-19-related energy demand changes. *NPJ Climate and Atmospheric Science, 4,* 45.

Kim, S., Bae, H., & Kim, H. (2024). A diagnostic and therapeutic dilemma: giant multifocal retroperitoneal dedifferentiated liposarcoma with dual heterologous components. *Archives of International Journal of Cancer and Allied Sciences, 4*(2), 1–5. doi:10.51847/5JnC3jAkZz

Ku, J. K., Um, I. W., Jun, M. K., & Kim, I. H. (2023). Clinical management of external apical root resorption using amnion membrane matrix and Bio-Dentine. *Journal of Current Research in Oral Surgery, 3,* 1–5. doi:10.51847/lOSwt6Qzpv

Landry, M., Spinella, M., Kumaran, K., Levesque, V., & Tyebkhan, J. M. (2024). Studying the effectiveness of mindfulness intervention on the stress of mothers with premature infants. *Journal of Integrated Nursing & Palliative Care, 5,* 48–54. doi:10.51847/YRsdPlmIDO

Lazzarini, S. G., Cabral, S., & Firpo, S. (2022). Why are counterfactual assessment methods not widespread in outcome-based contracts? A formal model approach. *Journal of Public Administration Research and Theory, 32*(3), 509–525.

Lee, S., Kim, J., & Byun, G. (2023). The interplay of political skill, ethical leadership, and leader-member exchange in shaping work outcomes. *Annals of Organizational Culture, Communications and Leadership, 4,* 45–53. doi:10.51847/vAKE892Paf

Li, C. X., Zhang, L., Yan, Y. R., Ding, Y. J., Lin, Y. N., Zhou, J. P., Li, N., Li, H. P., Li, S. Q., Sun, X. W., et al. (2024). Exploring advanced diagnostic techniques for salivary gland disorders: a narrative overview. *Asian Journal of Current Research in Clinical Cancer, 4*(1), 1–10. doi:10.51847/uN2cjdmOP8

Lin, Y. C., Stone, A. B., Byatt, G., & Rotche, L. (2024). How is counterfactual thinking integrated in organizational risk and resilience practices? *Journal of Risk Research, 27*(1), 1–20.

Liu, H., Xie, X., & Chen, Q. (2024). Determinants of practice: Exploring healthcare providers' beliefs and recommendations for cardiac rehabilitation in China. *Annals of Pharmacy Education & Safety in Public Health Advocacy, 4,* 63–74. doi:10.51847/UcQWoStr3h

Liu, M., Tang, Q., Wang, Q., Xie, W., Fan, J., Tang, S., Liu, W., Zhou, Y., & Deng, X. (2022). Studying the sleep quality of first pregnant women in the third trimester of pregnancy and some factors related to it. *Journal of Integrated Nursing & Palliative Care, 3,* 1–6. doi:10.51847/K1PUWsJ24H

Manole, F., Mekeres, G. M., & Davidescu, L. (2023). Genetic insights into allergic rhinitis: a comprehensive review. *Interdisciplinary Research in Medical Sciences Special, 3*(1), 39–44. doi:10.51847/GDXePBjkMJ

Mennig, P., & Sauer, I. (2025). Revisiting the impact of decoupled subsidies on farm performance: a counterfactual analysis using microdata. *Agricultural Economics, 56*(1), 45–62.

Muresan, G. C., Hedesiu, M., Lucaciu, O., Boca, S., & Petrescu, N. (2023). Evaluation of bone turnover indicators before dental implant insertion in osteoporotic patients: A case-control investigation. *Journal of Current Research in Oral Surgery, 3,* 27–32. doi:10.51847/P4EfMAbJVb

Ncube, M., Sibanda, M., & Matenda, F. R. (2023). The influence of AI and the pandemic on BRICS nations: South Africa's economic performance during crisis. *Annals of Organizational Culture, Communications and Leadership, 4,* 17–24. doi:10.51847/lrMvYTE3OF

Nguyen, V. C. T., & Le, H. Q. (2022). Exploring the link between globalization and economic growth in Vietnam. *Annals of Organizational Culture, Communications and Leadership, 3,* 16–26. doi:10.51847/YlZDW79HQG

Nkosi, T., & Dlamini, A. (2023). Limited predictive performance of existing amisulpride PopPK models: external validation and proposal of model-based remedial regimens for non-adherence. *Pharmaceutical Sciences & Drug Design, 3,* 53–66. doi:10.51847/iAz1QEBpk0

Oliphant, Z., Gazmararian, A. F., Hubler, M., Furceri, D., Hannan, S. A., Igan, D., et al. (2023). Review of counterfactual land change modeling for causal inference. *Journal of Land Use Science, 18*(1), 54–78.

Osluf, A. S. H., Shoukeer, M., & Almarzoog, N. A. (2024). Case report on persistent fetal vasculature accompanied by congenital hydrocephalus. *Asian Journal of Current Research in Clinical Cancer, 4*(1), 25–30. doi:10.51847/0gjOEudJNr

Pynegar, E. L., Gibbons, J. M., Veríssimo, D., Asare, R., Baylis, K., Bicknell, J. E., et al. (2025). Selecting among counterfactual methods to evaluate conservation interventions. *Conservation Science and Practice, e70066.*

Saussay, A., & Sato, M. (2024). The impact of energy prices on industrial investment location: evidence from global firm level data. *Journal of Environmental Economics and Management, 127,* 102992.

Sefah, I. A., Chetty, S., Yamoah, P., Meyer, J. C., Chigome, A., Godman, B., & Bangalee, V. (2022). Assessment of medical students' knowledge, attitude, and practice regarding antibiotics and antimicrobial resistance: Insights from a cross-sectional study. *Annals of Pharmacy Education & Safety in Public Health Advocacy, 2,* 16–23. doi:10.51847/W7Qce5gHGM

Sheshadri, A., Kittiskulnam, P., & Johansen, K. L. (2024). Investigating the effects of physical activity on the amount of muscle cramp pain in hemodialysis patients. *Journal of Integrated Nursing & Palliative Care, 5,* 8–13. doi:10.51847/wZhaI3rJNj

Sonbol, H. S. (2023). Nutritional proteomics: a pathway to understanding and optimizing human health. *Journal of Medical Sciences Interdisciplinary Research, 3*(2), 45–64. doi:10.51847/SnZlWLL5go

Su, Z., Qin, M., & Hu, D. (2024). Impact of lecture versus group discussion-based ethics training on nurses' moral reasoning, distress, and sensitivity: a randomized clinical trial. *Asian Journal of Ethics in Health & Medicine, 4,* 81–96. doi:10.51847/iBvPMrJSLE

Tâlvan, E., Budișan, L., Mohor, C. I., Grecu, V., Berindan-Neagoe, I., Cristea, V., Oprinca, G., & Cristian, A. (2023). Interconnected dynamics among inflammation, immunity, and cancer–From tumor suppression to tumor onset, promotion, and progression. *Archives of International Journal of Cancer and Allied Sciences, 3*(1), 25–28. doi:10.51847/nbSWsJHJMZ

Teodorovicz, T., Lazzarini, S., Cabral, S., & Firpo, S. (2020). Why are counterfactual assessment methods not widespread in outcome-based contracts? A formal model approach. *Long Range Planning, 53*(5), 101956.

Treu, S., Muis, S., Dangendorf, S., & Wahl, T. (2023). Reconstruction of hourly coastal water levels and counterfactuals without sea level rise for impact attribution. *Earth System Science Data, 15*(3), 1121–1136.

Tricarico, L., Galimberti, A., Ausseil, A. G., Del Bello, F., et al. (2025). The counterfactual challenge: How machine learning can enhance policy evaluation. *Environmental Science & Policy, 162,* 103335.

Uneno, Y., Morita, T., Watanabe, Y., Okamoto, S., Kawashima, N., & Muto, M. (2024). Assessing the supportive care needs of elderly cancer patients at Seirei Mikatahara General Hospital in 2023. *International Journal of Social Psychology Aspects in Healthcare, 4,* 13–19. doi:10.51847/o4njwxvRSF

Vecchiato, R. (2019). Scenario planning, cognition, and strategic investment decisions in a turbulent environment. *Long Range Planning, 52,* 101894.

Welman, A., & Chima, M. D. (2023). Respecting autonomy in African communities: traditional beliefs and challenges for informed consent in South Africa. *Asian Journal of Ethics in Health & Medicine, 3,* 1–16. doi:10.51847/KmUs6uzoc1