

Natural Resource Management Under Climate Change: Economic Costs, Emissions, and Social Resilience

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Abstract

Natural resource management under climate change generates interdependent economic, social, and environmental impacts. However, the scientific evidence remains fragmented. This fragmentation limits the design of integrated policies capable of reducing vulnerability and preventing the degradation of natural capital. The objective of this study is to analyze recent scientific literature to assess how natural resource management in the context of climate change simultaneously influences economic stability, social resilience, and environmental sustainability. To this end, a systematic review of literature published in indexed journals on environmental economics, climate change, and natural resource management was conducted, selecting quantitative and mixed-methods studies that examine economic, social, or biophysical impacts associated with environmental degradation, extractive dependence, and adaptation and mitigation strategies. The review integrated research at macroeconomic, microeconomic, and ecological scales, organized using comparative matrices that allowed for the identification of common patterns in indicators of economic loss, emissions, natural capital depreciation, and effects on social welfare. Subsequently, a comparative analysis was conducted to detect relationships between management failures, social vulnerability, and long-term costs, as well as to identify conceptual, methodological, and geographical gaps in the literature. The results show that the degradation of natural resources under climate change produces simultaneous effects on macroeconomic stability, household income, and ecosystem resilience, increasing the costs of inaction when policies are designed sectorally. The evidence synthesized in this review indicates that dependence on extractive activities, limited productive diversification, and institutional weaknesses are frequently associated with greater economic and social vulnerability, particularly in communities dependent on natural resources. The reviewed studies also suggest that adaptation and mitigation strategies that incorporate participatory governance, social capital, and natural capital conservation may contribute to strengthening resilience. However, given the heterogeneity of methodologies, spatial scales, and indicators among the analyzed studies, these findings should be interpreted as evidence of consistent patterns rather than causal relationships. Therefore, integrated approaches that consider economic, social, and environmental dimensions represent a promising direction for sustainable natural resource management under climate change, although further empirical research is required to evaluate their effectiveness across different contexts.



Academic Editor: Dimitrios E. Tsismelis

Received: 7 June 2026

Revised: 25 July 2026

Accepted: 31 July 2026

Published: 7 August 2026

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Keywords: natural resource management; climate change; economic impacts; social resilience; natural capital; sustainable development

1. Introduction

Climate change has become a major determinant of economic, social, and environmental sustainability globally, profoundly altering the relationship between natural systems and productive activities [1,2]. Climate change is characterized by rising average temperatures, altered precipitation patterns, and more frequent extreme weather events. These changes are placing increasing pressure on natural resources. As a result, water availability, soil fertility, forest ecosystem stability, and energy security are being affected, with important implications for economic development and human well-being [3–5]. These changes not only represent an environmental problem but also constitute a growing macroeconomic risk, especially in regions whose productive structure depends heavily on the exploitation of natural resources and which have limited institutional capacity to respond to climate impacts [6,7].

The increasing human pressure on natural resources is closely linked to the prevailing development model, characterized by intensive energy and material use [8]. Historical evidence shows that global resource extraction has increased exponentially over the last century, driven by urbanization, industrialization, and rising per capita consumption [9]. In particular, fossil fuel use remains the primary driver of greenhouse gas emissions, despite progress in energy transition policies. Fossil fuel extraction is estimated to have increased twelvefold between 1900 and 2015, reaching levels close to 89 gigatons annually, while in recent years the energy sector has accounted for a significant proportion of national emissions in industrialized economies [10,11]. This pattern is consistent with the idea that the processes of extraction, transformation, and consumption of natural resources are directly related to climate change, generating a feedback loop in which environmental degradation increases economic and social vulnerability [12].

Economic literature has extensively documented that the relationship between abundant natural resources and development is not necessarily positive. Several studies describe the phenomenon known as the “resource curse,” whereby countries highly dependent on natural resource income tend to experience lower economic growth, weaker institutions, and higher levels of environmental degradation [13]. In the context of climate change, these structural vulnerabilities are exacerbated, as resource-dependent sectors are highly sensitive to climate variations, which reduces productivity, increases fiscal volatility, and limits public investment capacity [14,15]. Recent research even identifies a “carbon curse,” in which economies with a high share of the extractive sector in their gross domestic product exhibit higher levels of emissions and lower technological innovation, reinforcing environmentally unsustainable development trajectories [16,17].

From an environmental perspective, the degradation of natural resources is one of the main sources of greenhouse gas emissions [18,19]. Changes in land use, deforestation, agricultural expansion, and soil degradation alter biogeochemical cycles and release carbon stored in biomass and soils, reducing the capacity of ecosystems to act as natural carbon sinks [20,21]. It has been estimated that agricultural and forestry expansion in tropical regions generates around 2.6 gigatons of CO₂ annually, a significant proportion of which is associated with international demand for commodities such as meat, soy, and palm oil [20]. In highly sensitive ecosystems, such as peatlands, drainage and the lowering of the water table can lead to carbon losses exceeding 5 tons per hectare annually, demonstrating that the degradation of natural capital entails long-term cumulative environmental costs [21]. These

losses reduce the provision of essential ecosystem services, such as water regulation, carbon sequestration, and biodiversity conservation, thus limiting the potential for sustainable economic growth [22].

The economic consequences of these processes are significant and unevenly distributed across regions and social groups. In rural and semi-arid contexts, soil degradation and decreased water availability directly affect agricultural productivity and household income, generating losses that can reach between 30% and 50% in certain communities [23]. At the macroeconomic level, it has been estimated that environmental degradation can reduce agricultural gross domestic product in sub-Saharan Africa by between 1.8% and 3% annually [17], while in Latin American economies dependent on mining and other extractive resources, environmental externalities and the loss of ecosystem services represent costs equivalent to several percentage points of GDP [17–24]. These results show that environmental degradation associated with climate change should not be interpreted solely as an ecological problem, but as a factor that compromises financial stability, productivity, and social well-being [25].

The social dimension is another critical element in natural resource management under climate change. Recent evidence indicates that governance, social participation, and community-based approaches strengthen adaptive capacity, reduce vulnerability, and facilitate the implementation of climate adaptation strategies, particularly in communities highly dependent on natural resources [23,26,27]. These mechanisms also enhance social resilience and improve the capacity of local populations to respond effectively to climate-related risks [23,27].

Despite the growing body of research on climate change, natural resources, and development, the literature has significant limitations. Many studies analyze economic, social, and environmental impacts separately, making it difficult to understand the cumulative effects of natural capital degradation and to assess the total cost of inaction. Furthermore, there is considerable heterogeneity in the indicators used to measure economic losses, emissions, investment in adaptation, and social vulnerability, which hinders comparisons between regions and limits the usefulness of the evidence for public policy design [28]. This fragmentation of knowledge justifies the need for integrative studies that synthesize quantitative results and establish comparable ranges of costs and benefits associated with different natural resource management strategies.

Despite the growing literature on climate change and natural resource management, existing review studies have generally examined economic, environmental, and social impacts separately. Consequently, limited attention has been given to understanding how environmental degradation, greenhouse gas emissions, economic costs, adaptation investments, and social resilience interact within a single socio-ecological system. This review addresses that gap by providing an integrated synthesis of evidence published between 2015 and 2025 through a PRISMA-guided systematic review and a PICO-based analytical framework [29].

To address this fragmentation, the present study adopts an integrated conceptual framework that links the economic, environmental, and social dimensions of natural resource management under climate change.

Natural resource management under climate change is conceptualized as a coupled socio-ecological system in which environmental degradation, economic losses, adaptation investments, and social resilience are interconnected rather than independent processes. Climate change simultaneously affects natural systems and productive activities, generating feedback mechanisms whereby environmental degradation increases economic vulnerability, while inadequate governance and resource dependence reduce adaptive capacity [3,10,12]. Based on the evidence synthesized in previous studies, this review

conceptualizes inadequate natural resource management as an initial driver linking climate pressures with socioeconomic consequences that affect natural capital, economic stability, and social well-being [17,30,31].

Within this framework, unsustainable extraction patterns, land-use change, and weak institutional governance accelerate the degradation of natural capital and increase greenhouse gas emissions [18–21,32]. These environmental pressures generate economic impacts through reduced productivity, loss of ecosystem services, depreciation of natural capital, and increased costs associated with climate-related damages [4,22,24,33]. At the same time, these impacts disproportionately affect communities dependent on natural resources by reducing income stability, increasing inequality, and limiting adaptive capacity, particularly in rural and vulnerable populations [23,27,34]. Consequently, environmental degradation, economic losses, and social vulnerability are viewed as interconnected processes within a broader climate–resource management system rather than as independent outcomes [3,10].

Adaptation investment is considered not only as a financial response to climate impacts but also as a mechanism capable of modifying vulnerability trajectories and reducing future economic losses [35–37]. Effective adaptation requires the integration of economic planning, ecosystem conservation, and inclusive governance, since isolated technical interventions may generate only limited benefits or even reinforce existing inequalities [6,27,28]. Investments in sustainable resource management, ecosystem restoration, productive diversification, and participatory decision-making can reduce future economic costs while strengthening social resilience and adaptive capacity [17,38–42]. Accordingly, sustainable natural resource management is understood as the outcome of interactions among environmental protection, economic efficiency, institutional capacity, and social inclusion.

Accordingly, this review adopts an integrated analytical framework in which economic costs, greenhouse gas emissions, adaptation investment, and social resilience are treated as interconnected dimensions of a broader sustainability pathway. This framework guided the formulation of the research questions and the synthesis of evidence presented in this review.

Figure 1 illustrates the integrated conceptual framework adopted in this review. The framework conceptualizes natural resource management under climate change as a dynamic interaction among environmental pressures, governance, adaptation investments, and different forms of capital (natural, human, and physical). Climate hazards influence natural capital and productive systems, while governance, institutional capacity, and financial investments determine the effectiveness of adaptation measures and the resilience of socio-ecological systems. This integrated perspective provides the theoretical basis for examining the relationships among environmental degradation, greenhouse gas emissions, economic costs, adaptation investment, and social resilience throughout the review.

Previous review studies have provided valuable evidence regarding the economic consequences of climate change and adaptation investments [3,13,35,37,38], environmental degradation and greenhouse gas emissions [3,20,21,31,33], and social vulnerability, governance, and resilience processes [10,23,27,28,40,41]. However, these dimensions have often been examined independently, limiting understanding of the complex interactions among resource degradation, economic costs, emissions, adaptation responses, and social resilience. The present review addresses this limitation by synthesizing these dimensions within a unified socio-ecological perspective.

Furthermore, previous syntheses have frequently been conducted at specific analytical scales, either focusing on macroeconomic effects, sectoral environmental impacts, or local adaptation experiences [3,10,23,35,36]. This fragmentation makes it difficult to identify the relationships between resource exploitation patterns, climate-related pressures, management strategies, and long-term resilience outcomes. The evidence synthesized in previous

studies indicates that climate change impacts emerge from interactions among ecological processes, economic structures, institutional conditions, and social vulnerability; however, these relationships are rarely integrated within a single analytical framework [10,13,32]. Therefore, the contribution of this systematic review is not merely to compile existing evidence, but to establish an integrated framework that connects economic impacts, environmental pressures, and social consequences associated with natural resource management under climate change.

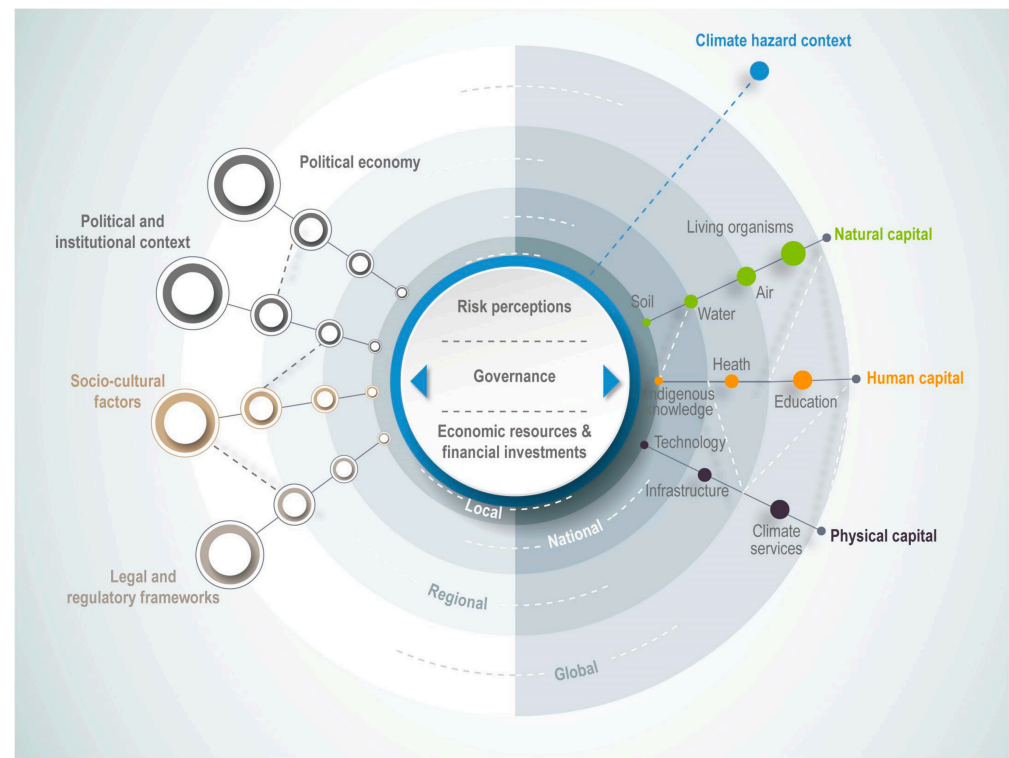


Figure 1. Social, institutional and environmental components that shape climate risk management.

Compared with previous reviews, this study extends existing approaches by combining the PRISMA methodology with a PICO-based research framework to systematically identify, classify, and compare evidence across different spatial scales, natural resource categories, and management strategies. This approach enables the identification of common mechanisms linking inadequate resource governance with economic losses, greenhouse gas emissions, reduced ecosystem resilience, and social vulnerability. Consequently, this review provides a multidimensional synthesis that moves beyond isolated assessments of climate impacts toward a more integrated understanding of sustainable natural resource management.

In this context, systematic reviews represent a fundamental methodological tool for consolidating the available evidence and generating robust conclusions. The use of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline ensures transparency in study selection, reproducibility of inclusion criteria, and rigor in results synthesis, reducing bias and improving the validity of conclusions [29]. Similarly, applying the PICO (Population, Intervention, Comparison, Outcome) approach facilitates the structuring of research questions, clearly identifying the study population, the type of intervention or policy analyzed, the comparison scenarios, and the economic, social, and environmental outcomes evaluated [43]. Combining both approaches is particularly relevant in interdisciplinary research, such as natural resource management under climate

change, where integrating information from economics, ecology, social sciences, and public policy is essential.

This study is justified by the need for integrated quantitative evidence to answer key questions for the formulation of sustainable policies. In particular, it is essential to estimate the economic cost associated with environmental degradation, analyze the relationship between resource exploitation patterns and greenhouse gas emissions, assess the level of investment allocated to adaptation, and determine how management strategies influence the social resilience of communities dependent on natural resources. Although numerous individual studies exist on these topics, the lack of a systematic synthesis limits the possibility of identifying global trends and establishing comparable ranges across regions and productive sectors.

Therefore, this study conducts a systematic review of literature published between 2015 and 2025 to evaluate the economic costs, greenhouse gas emissions, adaptation investments, and social resilience outcomes associated with natural resource management under climate change. The review synthesizes evidence across different geographical contexts and analytical scales to identify recurring patterns, knowledge gaps, and implications for sustainable policy design.

Understanding these macroeconomic costs and patterns of resource degradation is critical for sustainable development. Cities and their surrounding regions represent the main hubs of global consumption. The effective management of water, soil, and energy resources is therefore a key pillar supporting urban metabolism and regional resilience [44]. Consequently, local and regional governments are uniquely positioned and urgently called to lead integrated adaptation strategies. By optimizing resource flows and strengthening institutional frameworks, urban decision-makers can effectively mitigate the escalating economic losses and environmental pressures detailed in this study, thereby fostering socio-ecological resilience at the conurbation scale.

2. Materials and Methods

The conceptual framework presented in the Introduction provided the theoretical basis for formulating the review questions. Accordingly, the research questions were designed to examine the interactions among environmental pressures, economic consequences, adaptation responses, and social outcomes associated with natural resource management under climate change. To ensure a transparent and reproducible review process, the questions were structured using the PICO (Population, Intervention, Comparison, Outcome) framework.

2.1. Protocol and Focus Questions

This systematic review was developed from the rigorous formulation of research questions, using the PICO (Population, Intervention, Comparison, Outcome) format as its methodological basis. PICO is widely recommended for structuring evidence-based reviews [45]. The PICO method is an effective tool for precisely defining the scope of research, establishing clear criteria for searching, selecting, and analyzing available evidence. Using this approach helps reduce bias, improve methodological transparency, and ensure the reproducibility of the review process [46]. Furthermore, it facilitates the identification of relevant studies that address complex problems from multidimensional perspectives, as is the case in the analysis of natural resource management in the context of climate change [3].

According to the PICO approach, a well-structured research question should integrate four fundamental components. First, the Population or Problem (P) defines the phenomenon, system, or group under study and is associated with the dependent variable, insofar as it reflects the effects of the problem being analyzed. In this review, the central focus

is formulated from the following question: What natural resources or socio-environmental systems are affected by climate change and inadequate management practices? This component encompasses strategic resources such as water, soil, forests, biodiversity, energy, and minerals, as well as the ecosystems and human communities that depend on them, recognizing their interdependence and vulnerability to climate pressures [47,48].

The second component corresponds to Intervention (I), understood as the set of actions, policies, or strategies aimed at addressing the identified problem. In this context, the guiding question is: what sustainable management, adaptation, or mitigation measures are implemented to reduce the economic, social, and environmental impacts of climate change on natural resources? The interventions considered include public policies, economic instruments, the adoption of clean technologies, environmental governance mechanisms, and community adaptation strategies, all of which seek to strengthen the resilience of socio-ecological systems [49,50].

Comparison (C) allows for contrasting scenarios, regions, or sectors with different levels of implementation of climate-sustainable management strategies. In this sense, the question is posed: what differences are observed between communities, regions, or sectors that apply sustainable management measures versus those that lack them? This component facilitates the evaluation of the relative effectiveness of different management approaches and the role that institutional, economic, and social factors play in the observed results [51].

Meanwhile, the Outcome (O) component focuses on the effects of both implementing and not implementing interventions. The associated question is: what are the economic, social, and environmental impacts linked to the management or degradation of natural resources in climate change scenarios? The outcomes are analyzed using indicators such as economic losses, GDP variations, levels of environmental investment, CO₂ emissions, community resilience, and ecosystem quality, providing a comprehensive view of the consequences of climate change [52].

The application of the PICO method allowed for the precise definition of research questions and guided the systematic review toward the important research themes. The defined components are summarized in Table 1.

Table 1. Application of the PICO approach in the analysis of the sustainability and economic impact of natural resources.

Component	Description
Population	Socio-ecological systems, territories, and human communities dependent on natural resources that are exposed to climate change impacts and management challenges.
Intervention	Sustainable natural resource management strategies, climate adaptation and mitigation measures, environmental policies, governance mechanisms, and technological solutions aimed at reducing climate-related impacts.
Comparison	Scenarios or regions without implementation of management measures, with conventional management practices, or with different levels of climate-sustainable management approaches.
Results	Estimates of the economic cost (USD or % of GDP), levels of environmental investment, CO ₂ emissions reduction and social impacts associated with the management of natural resources.

Research Questions

Based on the PICO protocol and the specialized literature, the following guiding questions for the systematic review were formulated:

1. What is the estimated economic cost, expressed in GDP losses and in the monetary value of natural resources, resulting from environmental degradation associated with climate change in different regions of the world?

2. How are the patterns of extraction, use, and exploitation of natural resources related to greenhouse gas emissions generated by productive sectors?
3. What level of investment is allocated annually to adaptation measures and sustainable management of natural resources in the face of the effects of climate change?
4. How do climate change management strategies affect the social conditions and resilience of communities dependent on natural resources?

2.2. Selection of Items

The guidelines established by the PRISMA methodology were followed in preparing this systematic review (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), in order to guarantee the transparency, reproducibility, and methodological rigor of the scientific literature selection process. The literature search was initially conducted in the Scopus database, selected for its broad coverage of peer-reviewed scientific literature in the areas of environmental economics, natural resource management, and climate change. The search strategy was structured using keywords and Boolean operators (AND, OR), combining terms such as “economic impact”, “natural resources”, “climate change”, “emissions”, “environmental investment” and “resource management”. As a result of this initial search, 565 records were identified. Subsequently, inclusion criteria were applied to refine the results, restricting the selection to articles published in English between 2015 and 2025, in order to ensure the relevance and currency of the scientific evidence analyzed. After this refinement, a total of 424 records were obtained.

Because the literature search was conducted exclusively in the Scopus database, no duplicate records originating from multiple databases were expected. Nevertheless, the retrieved records were exported and verified for potential duplicates using the identification tools available in Scopus, and no duplicate entries requiring removal were detected. The study selection process was subsequently conducted according to the PRISMA 2020 guidelines. Two independent reviewers performed the screening of titles, abstracts, and full texts. Any disagreements regarding eligibility decisions were resolved through discussion between the reviewers and, when consensus was not reached, through consultation with a third reviewer.

A screening process was then carried out by reviewing titles, which allowed for the exclusion of 356 articles that did not align with the research’s thematic focus. Thus, 68 articles advanced to the abstract review stage. During the abstract evaluation, more specific exclusion criteria were applied, resulting in the rejection of 23 studies because they were not related to the management of renewable natural resources (8 articles), did not answer the research questions (6 articles), or did not include economic, quantitative, or environmental investment-related information (9 articles). As a result, 45 articles were selected for full-text evaluation.

The detailed content review allowed for the evaluation of the methodological quality and relevance of the studies, culminating in the final selection of 30 articles that comprise the analytical corpus of this systematic review. The complete process of identifying, screening, eligibility, and selecting the studies is presented in the corresponding PRISMA diagram (Figure 2), developed according to the updated PRISMA 2020 guidelines.

Scopus database. The combination of keywords that provided the most relevant results was: TITLE-ABS-KEY (“economic cost” OR “economic impact” OR “cost of degradation” OR “environmental cost”) AND (“natural resources” OR “water” OR “soil” OR “forests”) AND (“climate change” OR “global warming”) AND (loss OR degradation OR depletion) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE, “English“)).

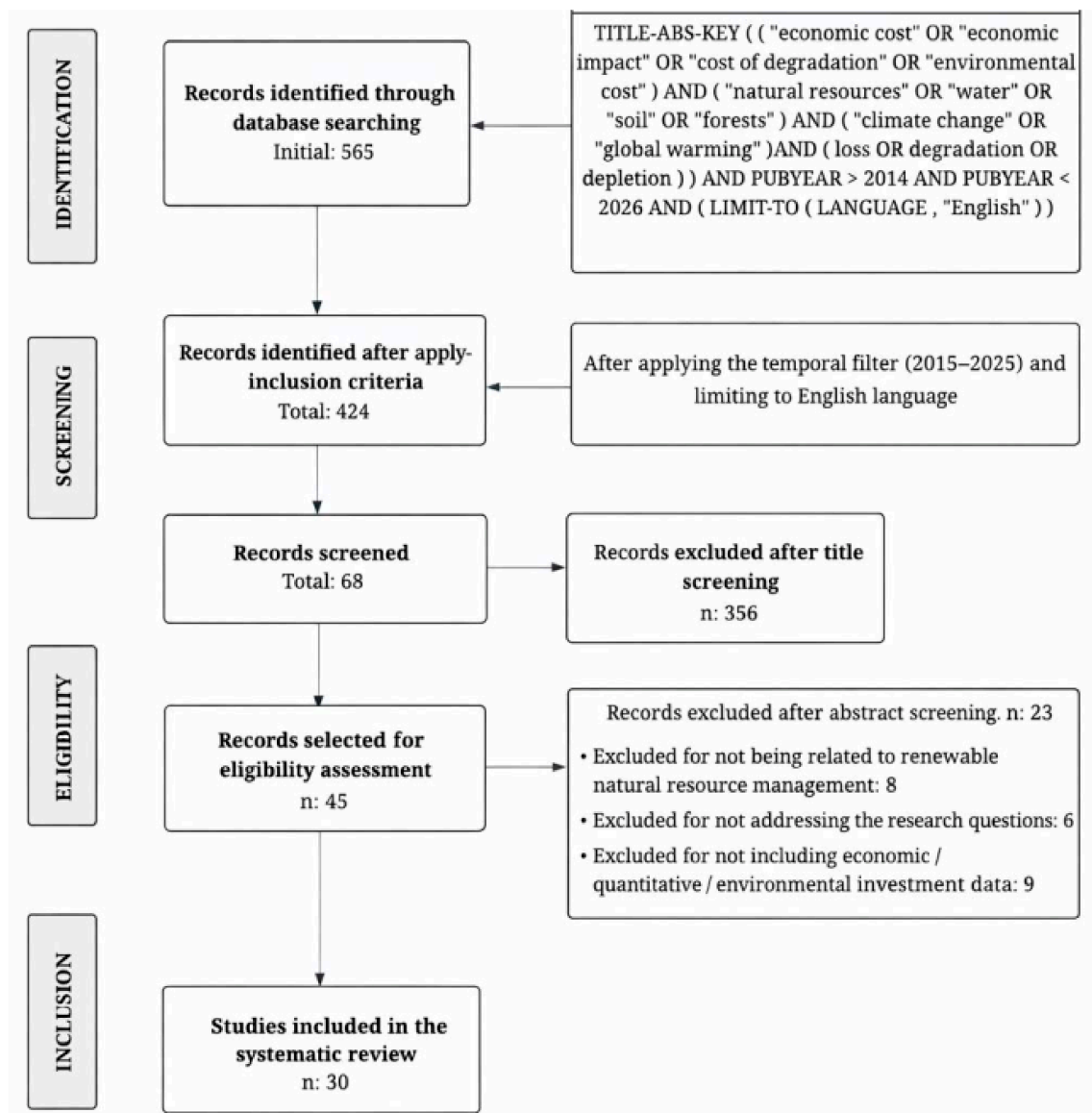


Figure 2. Selection of articles for the systematic review on the management of natural resources in the context of climate change: economic, social and environmental implications using the PRISMA methodology.

Scopus was selected because it is one of the largest multidisciplinary citation databases and provides extensive coverage of peer-reviewed literature in environmental sciences, sustainability, economics, and climate change. Comparative studies have shown a substantial overlap between Scopus and Web of Science, while also indicating that Scopus generally covers a larger number of journals across disciplines, making it a suitable source for bibliometric and systematic review studies [53,54].

2.3. Methodological Quality Assessment

The methodological quality of the included studies was assessed using an adapted critical appraisal rubric derived from the Joanna Briggs Institute (JBI) framework for analytical studies and evidence synthesis [55]. Five methodological domains were evaluated: (i) clarity of objectives, (ii) appropriateness of methodology, (iii) transparency of data sources, (iv) robustness of analytical methods, and (v) consistency between results and conclusions.

Each criterion was scored on a three-point scale: 0 = criterion not met, 1 = partially met, and 2 = fully met. Total scores ranged from 0 to 10 points. Studies scoring 8–10 were

classified as high quality, those scoring 5–7 as moderate quality, and those scoring below 5 as low quality. Only studies classified as moderate or high quality were retained for the final synthesis.

The complete quality assessment rubric is provided in Supplementary Material Table S1.

2.4. Data Extraction

Data were systematically extracted from all studies included in the final sample using a standardized extraction matrix, following established recommendations for evidence synthesis and systematic reviews [38,45]. The matrix recorded publication year, study location, natural resource analyzed, climate change issue addressed, methodological approach, indicators, and the main economic, environmental, and social outcomes [38,46].

The extracted information was organized into three analytical dimensions: (i) economic impacts, including GDP losses, valuation of natural capital, household income, and adaptation costs; (ii) environmental impacts, including greenhouse gas emissions, resource degradation, carbon losses, and ecosystem service changes; and (iii) social impacts, including vulnerability, equity, adaptive capacity, and community resilience. This classification is consistent with multidimensional sustainability assessment frameworks that integrate economic, environmental, and social perspectives [3,47,48].

Additional information was extracted following the PICO framework, including the population/problem, intervention or management strategy, comparison scenario, and reported outcomes [45,46]. Quantitative indicators were standardized whenever possible to facilitate comparisons across studies, whereas qualitative information was coded into recurring themes related to governance, institutional capacity, resource dependence, and sustainability strategies using thematic synthesis procedures [38,46].

The extracted data were synthesized through comparative tables and narrative analysis to identify common patterns, methodological differences, geographical gaps, and relationships between natural resource management, climate change impacts, and socioeconomic resilience. Narrative synthesis was selected because it is appropriate for integrating evidence from studies with heterogeneous methodologies, indicators, and study contexts [38,46].

In addition to the qualitative synthesis of the selected studies, an evidence map was developed to visualize the relationship between extractive dependence and greenhouse gas emission impacts reported in the literature. For the development of the evidence map presented in Figure 3, studies were classified according to two qualitative dimensions derived from their reported findings: (i) the degree of dependence on extractive or resource-intensive activities and (ii) the relative magnitude of greenhouse gas emission impacts reported by each study. These classifications were based exclusively on the evidence and descriptions provided in the original publications and were not obtained from a new statistical analysis or from a harmonized quantitative dataset. Therefore, the evidence map represents a qualitative synthesis of reported relationships rather than an empirical model. The objective of this visualization was to identify recurring patterns across different sectors and geographical scales.

2.5. Data Synthesis and Evidence Integration

Due to the interdisciplinary nature of research on natural resource management and climate change, substantial heterogeneity was expected among the included studies regarding geographical contexts, methodological approaches, indicators, and analytical scales. Therefore, a quantitative meta-analysis was not considered appropriate. Instead, a structured narrative synthesis approach was applied to integrate the evidence from the selected studies.

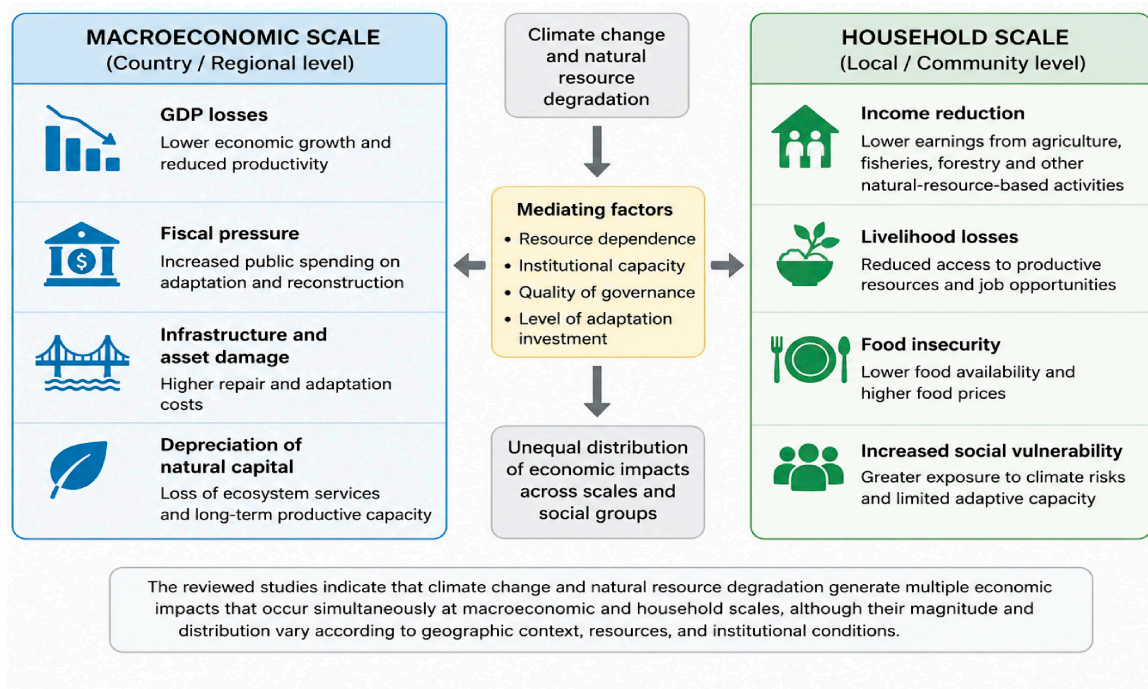


Figure 3. Conceptual framework of climate-related economic impacts across macroeconomic and household scales derived from the reviewed literature. Note: This framework does not represent a quantitative estimation of economic losses but summarizes recurring impact pathways identified in the reviewed studies.

The synthesis process involved systematically coding and organizing the extracted information according to predefined analytical dimensions derived from the PICO framework, including the socio-ecological system addressed, natural resource management strategies, comparison scenarios, and reported economic, environmental, and social outcomes.

The findings were subsequently organized into comparative matrices to identify recurring patterns, convergent evidence, and knowledge gaps across studies. The synthesis focused on four interconnected dimensions representing different stages of the climate–resource management–society pathway: (i) environmental pressures generated by resource exploitation and associated greenhouse gas emissions; (ii) economic consequences resulting from ecosystem degradation and loss of natural capital; (iii) adaptation investments aimed at reducing future risks and restoring resource productivity; and (iv) social resilience outcomes reflecting the capacity of communities to respond and adapt.

Because the included studies used different indicators and methodological approaches, comparisons were performed through conceptual harmonization rather than direct numerical comparison. For example, economic outcomes were interpreted using comparable indicators such as monetary losses, income reductions, gross domestic product impacts, and natural capital depreciation. Environmental outcomes were compared through indicators related to emissions, land-use change, and ecosystem degradation.

Overall conclusions were derived only when consistent patterns were identified across multiple studies, geographical contexts, or analytical scales. Studies with higher methodological quality, as determined through the quality assessment process, were given greater consideration during interpretation. This approach ensured that the identified trends were based on systematic evidence integration rather than subjective interpretation.

3. Results

Before presenting the results for each research question separately, it is important to emphasize that the selected studies do not represent four independent lines of evidence. Instead, the synthesis revealed a common socio-ecological pathway in which unsustainable

natural resource management simultaneously generates environmental degradation, increases greenhouse gas emissions, produces economic losses, and reduces social resilience. Accordingly, the following sections are organized according to the review questions, but the evidence is interpreted as interconnected dimensions of the same climate–resource management system rather than as isolated outcomes.

3.1. Quality Assessment and Risk of Bias

The methodological quality assessment indicated that all 30 included studies met the minimum quality threshold established for this review. Specifically, 21 studies (70%) were classified as high quality, with scores ranging from 8 to 10, while the remaining 9 studies (30%) were classified as moderate quality, with scores between 5 and 7. No studies were categorized as low quality or excluded due to critical methodological limitations. The quality appraisal process was based on criteria adapted from the Joanna Briggs Institute (JBI) critical appraisal framework, which is widely used to assess the methodological rigor and internal validity of studies included in evidence syntheses [55].

The risk of bias assessment revealed predominantly low to moderate levels of bias across the included studies. Selection bias was rated as low in 22 studies and moderate in 8 studies, while reporting bias was assessed as low in 25 studies and moderate in 5 studies. Methodological bias was identified as low in 18 studies and moderate in 12 studies, whereas outcome reporting bias was rated as low in 24 studies and moderate in 6 studies. No study was classified as having a high risk of bias in any of the evaluated domains. Assessing risk of bias is a fundamental component of systematic reviews because it facilitates the interpretation of findings, supports the evaluation of evidence reliability, and helps explain potential heterogeneity among studies [55,56].

The most common limitations observed among the reviewed studies were the geographical concentration of research in specific regions, the use of heterogeneous economic indicators, and differences in temporal scales and analytical approaches. Nevertheless, most studies employed transparent data sources, clearly documented methodologies, and reproducible analytical procedures, supporting the overall robustness and reliability of the evidence synthesized in this review.

3.2. Q1: What Is the Estimated Economic Cost, Expressed in GDP Losses and in the Monetary Value of Natural Resources, Derived from Environmental Degradation Associated with Climate Change in Different Regions of the World?

The integrated analysis of the selected literature shows that the economic cost associated with the degradation of natural resources under climate change scenarios is high, persistent, and heterogeneous across regions, sectors, and scales of analysis. The evidence synthesized in Table 2 shows that these costs can be expressed both in terms of losses in gross domestic product (GDP) and in the monetary depreciation of natural capital and the direct reduction in household welfare, confirming that the economic impacts of climate change are not only environmental but also structural and multidimensional [4,23,24].

At the macroeconomic level, the literature agrees that environmental degradation induced by climate change generates significant GDP losses and increases the fiscal vulnerability of states, especially in economies highly dependent on primary sectors [13,35,36,57]. The results presented in Table 2 show that, in highly vulnerable contexts, the cumulative effects can reach critical magnitudes. Aragie et al. [35] estimate that in Ethiopia, climate shocks combined with inefficient water and energy management could generate cumulative losses of close to 17% of GDP by 2040, constituting a systemic shock that exceeds the state's fiscal capacity to respond. Similarly, Cordier et al. [36] show that in Arctic regions, the cost of adapting infrastructure to permafrost thaw can be equivalent to 14.6% of regional GDP, jeopardizing the economic viability of productive activities. These results suggest

that the lack of early investment in sustainable natural resource management increases future public spending, shifting fiscal resources from social policies to reactive adaptation measures. This aligns with the findings of Hallegatte et al. [37] and the IPCC [3], who warn that climate inaction raises long-term economic costs.

A second pattern reported in the reviewed literature corresponds to threshold effects associated with high levels of extractive dependence, beyond which the exploitation of natural resources ceases to generate net benefits and becomes a source of macroeconomic vulnerability. According to Nwani et al. [13], when fossil resource income exceeds approximately 12.18% of GDP, a reduction in economic growth, greater emissions intensity, and institutional weakening are observed, a phenomenon associated with the so called “resource curse.” Table 2 shows that this threshold coincides with contexts characterized by low productive diversification, scarce investment in resilient infrastructure, and a lack of stabilization funds. Similar evidence is observed in sub-Saharan Africa, where Dimnwobi et al. [57] estimate that environmental degradation reduces annual agricultural GDP by between 1.8% and 3%, affecting food security and the stability of rural incomes. Recent studies confirm that the combination of extractive dependence and climate change amplifies economic volatility and limits adaptive capacity, especially in countries with weak institutions [32,58,59].

Table 2. Economic and physical costs and their management implications by region and resource.

Dimension	Impact Indicator	Main Implication	Reference
Macroeconomics	−17% GDP by 2040	Economic vulnerability due to low diversification and limited resilience investment	Aragie et al. [35], Ethiopia
	>12.18% GDP resource dependence	Resource curse and institutional weakness	Nwani et al. [13], Global
	14.6% regional GDP adaptation cost	High infrastructure vulnerability in climate-risk areas	Cordier et al. [36], Arctic
	5–20% GDP loss by 2100 (without adaptation)	Long-term costs of climate inaction	IPCC [3], Global
	2–6% annual GDP loss	Reduced growth and higher reconstruction costs	Hallegatte et al. [37], Developing countries
	Long-term growth reduction	Natural capital depreciation	Dasgupta [30], Global
Microeconomics	−30% to −50% household income	Increased rural poverty and livelihood losses	Gichangi et al. [23], Kenya
	−1.8% to −3% agricultural GDP	Declining agricultural productivity	Dimnwobi et al. [57], Sub-Saharan Africa
	Increased rural poverty	Loss of livelihood assets from land degradation	Barbier & Hochard [34]
	Lower labor income	Social costs exceed private benefits	Zhao et al. [17], Latin America
	Higher health and food expenditures	Increased household vulnerability	Sánchez Rodríguez [32]

Table 2. *Cont.*

Dimension	Impact Indicator	Main Implication	Reference
Natural capital and externalities	US\$ 23,464 ha ⁻¹ forest value loss	Forest degradation reduces economic value	Mohr et al. [4], Europe
	5890 kg C ha ⁻¹ yr ⁻¹ loss	Carbon depletion and higher emissions	Heikkinen et al. [21], Finland
	Social cost > private benefit (mining)	Environmental and health externalities	Cañar & Loor [60]
	Ecosystem services losses (trillions USD yr ⁻¹)	Declining natural capital stocks	Costanza et al. [33]
	Reduced future productive capacity	Irreversible ecosystem degradation	IPBES [31], Global

Although the reviewed studies consistently report substantial economic costs associated with natural resource degradation, important methodological differences limit direct comparisons. Macroeconomic studies generally estimate losses through GDP projections and integrated assessment models, whereas microeconomic analyses focus on household income, productivity, or ecosystem-service valuation. Consequently, reported impacts vary not only because of regional conditions but also because of differences in analytical scale, valuation methods, and time horizons. For example, studies conducted at national scales tend to emphasize fiscal and growth effects, while local-scale studies reveal stronger impacts on household welfare and livelihood security. These methodological differences help explain part of the heterogeneity observed across regions and highlight the need for more standardized metrics for assessing climate-related economic losses.

At the microeconomic level, the reviewed studies indicate that climate-related impacts are unevenly distributed among social groups and frequently affect households whose livelihoods depend directly on natural resources. Figure 3 summarizes the different pathways through which climate change and environmental degradation generate economic consequences at both macroeconomic and household scales. These impacts include GDP losses, fiscal pressures, and natural capital depreciation at broader scales, as well as income reduction, livelihood disruption, and increased vulnerability at the household level. In semi-arid regions of Kenya, Gichangi et al. [23] document reductions of between 30% and 50% in household income due to soil fertility loss and increased droughts, reflecting the lack of agricultural insurance, social safety nets, and sustainable soil management policies. This pattern aligns with that reported by Barbier and Hochard [34], who note that environmental degradation disproportionately affects poor rural households by reducing their access to natural assets essential for livelihoods.

Furthermore, the reviewed literature indicates that current management models tend to internalize economic benefits at the aggregate level while externalizing costs at the local level. In Latin America, the impacts associated with mining and deforestation generate social costs that outweigh the private benefits of extraction, affecting public health, labor productivity, and social cohesion [17,60]. This finding aligns with Dasgupta's [30] argument that the undervaluation of natural capital in national accounts leads to economic decisions that appear profitable in the short term but generate net losses in the long term.

In addition to monetary losses, evidence shows a significant physical depreciation of natural capital, with cumulative and irreversible economic effects. The data included in Table 2 indicate that carbon loss in soils and forests represents an ecological depletion of capital that reduces future productive capacity. Heikkinen et al. [21] estimate losses of up to 5890 kg of carbon per hectare per year in cultivated peatlands in Finland, while

Mohr et al. [4] report that the increase in fires, pests, and forest disturbances in Europe has steadily increased forest management costs, reducing the net economic value of forests as productive assets. These losses of natural stock, rather than economic flow, limit the possibilities for future development, as also noted by Costanza et al. [33] and IPBES [31], who warn that ecosystem degradation reduces the capacity of economies to sustain long-term growth.

The combined analysis of Table 2 and Figure 3 suggests a structural pattern of inefficiency in natural resource management under climate change conditions. First, there is an asymmetrical approach to risk management, where current policies prioritize macroeconomic stability but shift the costs onto rural households and ecosystems. Second, there is poor management of natural capital, characterized by intensive exploitation without adequate mechanisms for replenishment, regulation, or adaptation. Third, the evidence shows that the greatest economic costs do not stem solely from climate change itself, but rather from the combination of climate change and extractive management models, weak regulatory frameworks, and insufficient investment in adaptation [31,32].

These cost patterns emerge from the interaction between environmental degradation and institutional management failures, and were consistent across geographical contexts regardless of the specific resource analyzed, confirming that weak governance and extractive dependence are structural rather than regional drivers of long-term economic vulnerability.

3.3. Q2: How Are the Patterns of Extraction, Use and Exploitation of Natural Resources Related to the Greenhouse Gas Emissions Generated by the Productive Sectors?

Evidence across the reviewed studies shows a consistent relationship between natural resource extraction and greenhouse gas (GHG) emissions: this relationship is strong, persistent, and structural, but not exclusively technological, since it is also conditioned by institutional, regulatory, and management factors. The evidence synthesized in Table 3 shows that emission mechanisms originate in different areas of industrial, territorial, and macroeconomic decision-making, and that the intensity of emissions depends largely on the quality of governance and the production model adopted. Overall, the studies indicate that, in resource-dependent economies, economic growth remains strongly coupled with increased emissions, limiting the possibility of transitioning to low-carbon development pathways [13,16,61].

To clarify the causal pathways linking natural resource management and greenhouse gas emissions, the reviewed evidence was organized into three complementary mechanisms. First, technological mechanisms refer to the efficiency and carbon intensity of production systems, including energy sources, electrification levels, and the adoption of cleaner technologies. Second, institutional mechanisms relate to governance failures, regulatory limitations, economic incentives, and weak planning processes that allow carbon-intensive activities to persist. Third, scale mechanisms describe situations in which increases in extraction volumes, production expansion, or resource demand offset efficiency improvements and generate additional emissions. These mechanisms interact, but they represent distinct analytical pathways through which natural resource management decisions influence emission outcomes.

In the field of industrial and energy management, the literature shows that the extraction and processing of minerals and fossil fuels constitute one of the main sources of global emissions. Zheng et al. [61] estimate that extractive activities and their supply chain can account for around 15% of global emissions, due to the high energy consumption of heavy machinery, transportation, and methane leaks. Table 3 shows that this impact depends not only on the type of resource but also on the energy structure used, since the persistence of fossil fuel-based energy sources increases the carbon intensity of the entire production chain. This result coincides with that of Azam et al. [62], who show that in G20 countries,

mining maintains a high carbon footprint due to the delay in the electrification of processes and the low adoption of renewable energies.

A second identified mechanism is the so-called scale effect, whereby increases in technological efficiency are outweighed by the growth in total extraction volume. Wang et al. [63] demonstrate that in metallic mineral processing, emissions can triple when production increases, even with the introduction of technical improvements. This phenomenon may contribute to explaining why policies focused solely on efficiency fail to reduce emissions when management prioritizes increased production volume. Similarly, Qin et al. [64] show that deep groundwater pumping for irrigation involves energy consumption of approximately 1896 PJ of fossil fuels globally, significantly increasing the carbon footprint of the agricultural sector. These results confirm that emissions intensity is associated with management decisions regarding the scale of exploitation rather than technological limitations.

In the territorial and biogeochemical sphere, evidence shows that land-use change is one of the main links between natural resource management and GHG emissions. Pendrill et al. [20] estimate that deforestation associated with the international trade of agricultural and forestry products generates approximately 2.6 gigatons of CO₂ per year, reflecting planning decisions that shift the environmental cost to less regulated tropical regions. Table 3 indicates that these emissions are not inevitable, but rather the result of failures in trade and territorial governance that allow the expansion of the agricultural frontier without considering global climate stability. In the agricultural sector, traditional practices also contribute to emissions. Sandeep et al. [65] show that prolonged flooding in rice cultivation generates significant methane emissions, while Heikkinen et al. [21] estimate that draining cultivated peatlands can release up to 5.89 tons of carbon per hectare, demonstrating that local soil management decisions can have global climate effects.

Table 3. Empirical evidence on failures in natural resource management and emissions generation in different sectors and regions.

Resource and Sector	Issuance Mechanism	Management Failure Identified	Author(s) and Region
Industrial and Energy Management			
Minerals and fossils (Mining)	High energy consumption and methane leaks; ~15% of global emissions associated with extraction.	Lack of transition to renewable energies in the extractive chain.	Zheng et al. [61], Global
Metallic Minerals (Processing)	Scale effect: emissions increase proportionally to the volume produced.	Priority to productive growth over technological efficiency.	Wang et al. [63], China
Groundwater (Agriculture)	Deep pumping with high fossil energy consumption (~1896 PJ).	Unsustainable aquifer management and low water efficiency.	Qin et al. [64], Global
Minerals (Mining)	High carbon intensity due to diesel and coal use.	Technological lag and low electrification of the sector.	Azam et al. [62], G20
Oil and gas (Energy extraction)	Direct emissions from combustion, venting and gas burning.	Energy subsidies and lack of climate regulation.	Fu et al. [66], Global
Heavy industry (Steel, cement)	Emissions from intensive energy use and thermal processes.	Lack of innovation in low-carbon processes.	IPCC [3], Global

Table 3. *Cont.*

Resource and Sector	Issuance Mechanism	Management Failure Identified	Author(s) and Region
Territorial and Biological Management			
Forests and soil (Agricultural trade)	Deforestation linked to international trade (~2.6 Gt CO ₂ /year).	Environmental outsourcing to tropical regions.	Pendrill et al. [20], Tropics
Soil (Rice)	Methane emissions from continuous flooding.	Traditional water management without CH ₄ reduction techniques.	Sandeep et al. [65], India
Peat Bodies (Soil)	Carbon oxidation by drainage (~5.89 t C/ha).	Agricultural planning without considering carbon reserves.	Heikkinen et al. [21], Finland
Agricultural expansion	Conversion of natural ecosystems to crops.	Lack of territorial planning and control of agricultural borders.	Sánchez Rodríguez [32]
Extensive livestock farming	CH ₄ emissions from enteric fermentation and land use change.	Production policies without environmental limits.	IPCC [3], Global
Macroeconomic management			
Oil and gas (National economy)	U-shaped relationship between resource dependence and emissions.	Fiscal dependence > 12.18% of GDP reduces green innovation.	Nwani et al. [13], Oil-producing countries
Extractive economies	Growth-emissions coupling.	Lack of productive diversification.	Balcilar et al. [16], Global
Infrastructure (Urbanization)	Energy and material intensive urban metabolism.	Expansive and resource-dependent urban design.	Krausmann et al. [9], Global
Public investment	Fossil fuel subsidies increase emissions.	Tax incentives that conflict with climate mitigation.	Arzaghi and Squalli [67], Global
Resource-based economic development	High carbon intensity in growth.	Lack of energy transition policies.	IPCC [3], Global

At the macroeconomic level, the literature agrees that the persistence of high emissions is closely related to the structure of economic incentives and fiscal dependence on natural resources. Nwani et al. [13] identify that when oil and gas revenues exceed approximately 12.18% of GDP, countries tend to delay the adoption of clean technologies and maintain carbon-intensive production models. The relationship between extractive dependence and greenhouse gas emissions has been documented across different economic sectors and geographical contexts. The evidence synthesized from the reviewed studies indicates that fossil fuel dependence, mineral extraction, land-use change, and other resource-intensive activities are frequently associated with higher greenhouse gas emission pressures. Figure 4 summarizes these relationships by presenting an evidence map of studies that have reported links between resource dependence and emission impacts.

The evidence landscape shown in Figure 4 suggests that the association between resource dependence and emissions is not restricted to a single economic sector but represents a recurring pattern identified in multiple studies. Fossil fuel dependence has been consistently linked with persistent carbon-intensive development pathways, while mining, material extraction, agricultural expansion, and land-use change have also been identified as important drivers of greenhouse gas emissions. However, the magnitude and mechanisms of these relationships vary among regions, economic structures, and resource governance contexts. Consequently, the patterns presented should be understood

as evidence-based tendencies reported in the literature rather than universal causal relationships. Similar results are reported by Balcilar et al. [16], who find that in resource-dependent economies, economic growth remains closely linked to increased emissions, even when technological improvements exist.

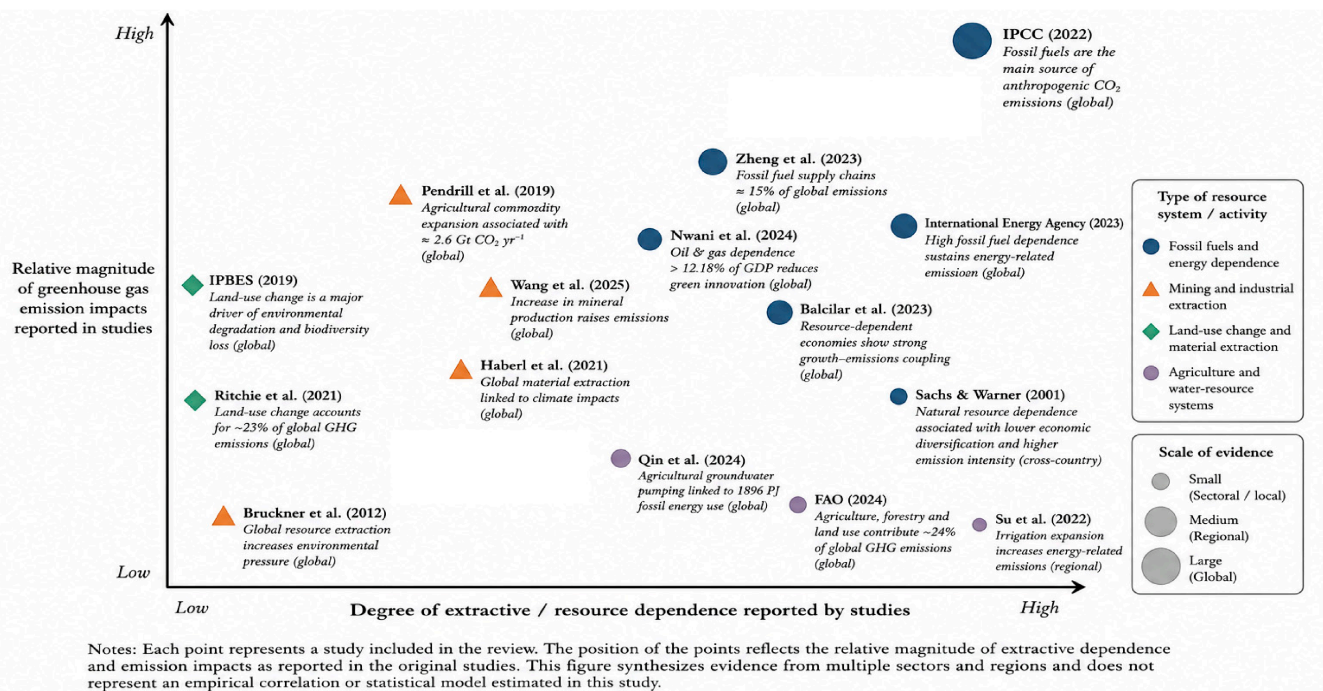


Figure 4. Evidence map illustrating the relationship between extractive dependence and greenhouse gas emission impacts reported in the literature. Each point represents a published study, while its position reflects the relative magnitude of extractive/resource dependence and emission impacts described in the original research. Bubble size indicates the spatial scale of evidence. This figure synthesizes patterns reported across multiple studies and does not represent an empirical correlation, regression analysis, or causal model developed in this review. Source: [3,13,16,20,31,48,61,63,64,68–73].

Figure 4 also allows us to interpret the relationship from a macroeconomic management perspective. When extractive dependence exceeds the threshold indicated in Table 3, productive diversification decreases, and the economic system becomes unable to decouple growth from pollution. This pattern confirms the “resource curse” hypothesis, according to which an abundance of natural resources can create incentives that favor intensive exploitation over technological innovation and sustainability [13,16]. Furthermore, Krausmann et al. [9] show that sprawling urbanization models increase the material metabolism of economies, generating constant flows of energy and materials that reinforce the link between economic growth and emissions.

These mechanisms were subsequently used to interpret the evidence synthesized from the reviewed studies. Accordingly, technological limitations, institutional conditions, and scale dynamics were analyzed separately to identify the specific pathways through which natural resource management decisions contribute to greenhouse gas emissions.

When considered collectively, the studies indicate that greenhouse gas emissions are better understood as a systemic consequence of natural resource management decisions than as a purely technological problem. Although the specific emission sources differ among sectors, the underlying mechanisms are remarkably consistent, linking resource dependence, governance limitations, and production models with increasing environmental pressures. This convergence across different contexts strengthens the interpretation that sustainable resource management represents a central leverage point for climate mitigation.

3.4. Q3: What Level of Investment Is Allocated Annually to Adaptation Measures and Sustainable Management of Natural Resources in the Face of the Effects of Climate Change?

The literature review shows that there is no single global budget for adaptation and sustainable natural resource management, but rather a wide variety of estimates based on abatement costs, fiscal requirements, financial flows, and avoided costs. Table 4 shows substantial variation in investment levels across regions and sectors. While some contexts require only limited investments that generate positive returns, highly vulnerable areas may require investments exceeding 10% of GDP. This variability reflects that climate investment depends not only on the magnitude of environmental risk but also on the fiscal capacity, productive structure, and institutional quality of each country [41,42,74].

In macroeconomic terms, several studies agree that early investment in adaptation significantly reduces economic losses associated with climate change. Aragie et al. [35] show that investment in water and energy infrastructure can mitigate up to 40% of projected economic losses in adverse scenarios, confirming that adaptation spending acts as a macroeconomic risk reduction mechanism. However, Table 4 shows that in highly exposed regions, investment requirements can reach levels that are difficult to sustain fiscally. Cordier et al. [36] estimate that in Arctic regions, adapting infrastructure to permafrost thaw may require investments equivalent to 14.6% of regional GDP, exceeding ordinary public financing capacity. Similarly, Aragie et al. [35] estimate that the cumulative cost of not investing in resilient irrigation systems can reach hundreds of billions of dollars, far exceeding any available annual budget.

The literature also shows that not all climate investment is equally economically efficient. A comparison of different mitigation technologies indicates that nature-based solutions typically have lower abatement costs than industrial technologies. Van Schoor et al. [75] estimate that biochar can reduce emissions at a cost of between \$471 and \$556 per tonne of CO₂ equivalent, while industrial carbon capture and storage can exceed \$678 per tonne, suggesting that current spending allocations do not always maximize the environmental impact per unit of capital invested. Similar results are reported by Khan et al. [41], who show that green infrastructure and watershed restoration can generate net economic benefits by reducing the costs associated with floods and droughts. Additionally, Zhao et al. [17] demonstrate that restoring degraded soils increases agricultural productivity and reduces the volatility of rural incomes, showing that investment in natural capital can simultaneously improve environmental resilience and economic performance.

Despite these positive returns, Table 4 confirms the existence of a persistent financing gap. Wei [39] shows that the increase in international climate finance has very low elasticity with respect to emissions reductions, with an estimated 1% increase in investment received reducing emissions by only 0.03%, suggesting structural problems in capital allocation. This low efficiency is associated with reactive approaches, a lack of institutional coordination, and technical limitations in recipient countries. Frank et al. [6] point out that, in the absence of clear regulatory frameworks and accountability mechanisms, resources tend to be concentrated on short-term projects or those with low structural impact, rather than financing profound productive transformations.

Evidence also shows that private financial mechanisms are beginning to shift capital allocation, although still insufficient to close the overall investment gap. Xu et al. [38] found that companies adopting efficient technologies or sustainable practices can access financing at preferential rates, incentivizing private investment in energy efficiency. Similarly, Su et al. [69] showed that the banking sector is incorporating climate risk into its lending decisions, reducing financing for carbon-intensive extractive activities. These changes suggest that the financial system is beginning to internalize environmental risk, but the current scale of these flows is still limited relative to global needs.

Another relevant finding is that the cost of maintaining natural resources increases progressively under climate change scenarios, raising investment requirements even to maintain current productivity levels. Mohr et al. [4] show that in Europe, forest management costs are steadily rising due to increased fires, pests, and climate disturbances, leading to higher annual expenditures to preserve the economic value of the resource. Similarly, Fathelrahman et al. [76] demonstrate that adaptation in fisheries and coastal systems requires high capital investments when physical infrastructure, such as artificial reefs, is chosen, compared to regulatory or sustainable management measures.

Finally, the literature agrees that the effectiveness of climate investment depends on its integration with economic development policies and natural resource management. Rahman et al. [40] show that approaches combining energy efficiency, ecosystem restoration, and productive diversification generate better economic and environmental outcomes than isolated strategies. Table 4 reflects that the greatest benefits are obtained when investment is not limited to compensating for damages, but rather transforms the productive structure toward models less dependent on the intensive exploitation of resources.

To improve the analytical organization of the evidence, the studies were grouped into three complementary categories: (i) adaptation costs, referring to the financial resources required to reduce climate vulnerability or the costs associated with inaction; (ii) climate finance effectiveness, evaluating the capacity of financial mechanisms to influence environmental outcomes and capital allocation; and (iii) mitigation and resilience returns, assessing the economic benefits and cost-effectiveness of investments that simultaneously reduce emissions and strengthen adaptive capacity.

From a policy perspective, the reviewed evidence suggests that adaptation investments should be prioritized according to both climate risk and cost-effectiveness rather than being allocated uniformly across sectors [3,35–37]. In highly vulnerable regions, public resources should focus on preventive measures that reduce long-term fiscal liabilities, including resilient infrastructure, ecosystem restoration, and sustainable water management [4,35,37,40]. The comparative evidence presented in Table 4 also indicates that nature-based solutions, such as biochar and ecosystem restoration, frequently provide greater economic returns per unit of investment than more capital-intensive technological alternatives, suggesting that these options should receive higher priority where local environmental conditions allow [39,40]. In addition, governments should strengthen project selection criteria by incorporating cost-benefit analysis, natural capital accounting, and long-term resilience indicators into public investment planning [30,40]. Finally, improving the effectiveness of climate finance requires transparent governance, performance-based allocation mechanisms, and stronger coordination between public investment, private finance, and local institutions to ensure that financial resources generate measurable reductions in climate vulnerability rather than simply increasing expenditure [6,38,73,77].

Overall, the evidence indicates that current levels of annual investment in adaptation and sustainable management are insufficient, unevenly distributed, and frequently inefficient. Although there are cases where investment generates positive economic returns and reduces climate vulnerability, the global allocation of capital remains dominated by reactive approaches, fiscal constraints, and institutional failures. Therefore, the literature converges on the idea that climate investment should be conceived not only as environmental spending but also as a structural transformation strategy aimed at reducing economic risks, protecting natural capital, and improving the resilience of production systems to climate change [6,36,38,40,67].

Table 4. Investment, climate finance, and mitigation evidence related to natural resource management under climate change.

Analytical Category	References	Region/Country	Type of Investment/Measure	Economic Indicator (Cost or Investment)	Financial Interpretation
Adaptation Costs	Cordier et al. [36]	Arctic (Regional)	Infrastructure Adaptation	14.6% of Regional GDP (Requirement)	Unsustainable level of investment for the local economy; it exceeds ordinary fiscal capacity.
Adaptation Costs	Aragie et al. [35]	Ethiopia	Public Infrastructure (Irrigation)	US\$ 534 Billion (Cost of Inaction)	The accumulated economic damage from not investing far exceeds any annual adaptation budget.
Adaptation Costs	Mohr et al. [4]	Europe	Forest Management	Millions of € per year (Increasing)	Forest maintenance costs increase due to climate-related disturbances and ecosystem degradation.
Adaptation Costs	Fathelrahman et al. [76]	United Arab Emirates	Fisheries and Marine Resources	High CAPEX (Infrastructure)	Investment in hard adaptation measures requires substantial upfront capital compared with regulatory alternatives.
Climate Finance Effectiveness	Wei [39]	Developing Countries	International Climate Finance	Elasticity: 0.03%	A 1% increase in climate finance is associated with only a 0.03% reduction in emissions, suggesting limited efficiency under weak governance conditions.
Climate Finance Effectiveness	Xu et al. [38]	China	Green Finance (Private Sector)	Preferential Interest Rate	Sustainable firms gain access to cheaper capital, encouraging private investment in environmental management.
Climate Finance Effectiveness	Su et al. [69]	Global	Banking Sector Risk Allocation	Climate Risk Provisions	Financial institutions increasingly redirect capital away from extractive activities due to climate-related financial risks.
Mitigation and Resilience Returns	Van Schoor et al. [75]	Southern Africa	Biochar vs. Carbon Capture and Storage	US\$ 471–556/tCO ₂ eq (Biochar); US\$ 678/tCO ₂ eq (CCS)	Nature-based mitigation solutions are approximately 25% more cost-effective than industrial carbon capture alternatives.
Mitigation and Resilience Returns	Xu et al. [38]	China	Energy Efficiency	Negative Marginal Cost (Savings)	Investments in energy-efficient technologies generate net economic benefits and recover initial costs rapidly.

An important pattern emerging from the reviewed literature is that adaptation investments should not be interpreted solely in terms of their monetary magnitude. Across the analyzed studies, investment effectiveness depends primarily on governance quality, institutional capacity, and integration with ecosystem conservation strategies. Consequently, higher expenditure alone does not necessarily translate into greater resilience unless investments are aligned with long-term sustainable resource management.

3.5. Q4: How Do Climate Change Management Strategies Affect the Social Conditions and Resilience of Communities Dependent on Natural Resources?

The reviewed literature shows that climate change management strategies have heterogeneous and, in many cases, contradictory social effects on communities dependent on natural resources. The outcomes depend not only on the type of measure implemented, but also on how these policies are designed, financed, and executed. The evidence summarized in Table 5 indicates that strategies can strengthen social resilience when they incorporate participatory governance, productive diversification, and the strengthening of social capital, but they can increase vulnerability when they rely exclusively on technical solutions or shift the cost of adaptation onto households [23,27,28,41,42].

Table 5. Impact of climate management strategies on resilience and social equity.

References	Context/Resource	Implemented Management Strategy	Impact on Social Conditions and Resilience
Kohlitz, Chong, and Willetts [27]	Water Management (Collection Systems)	Decentralized infrastructure (Rainwater tanks)	Generation of Inequality: Access depends on socioeconomic level. The poorest households bear greater maintenance burdens and have less water security, increasing their relative vulnerability.
Baccar et al. [28]	Local Governance (Community Resources)	Participatory approaches and institutional coordination	Strengthening Social Capital: Collective decision-making reduces tensions and facilitates the exchange of knowledge (social learning), improving real adaptive capacity.
Moser et al. [10]	Public Policies (Land Use/Energy)	Mitigation and adaptation regulations	trade -off: The measures can ensure long-term resilience, but generate exclusion or immediate social costs if the needs of local communities are not integrated into the design.
Murshed et al. [42]	Dependent Economy (Natural Resources)	Diversification and Education	Structural Resilience: Management that promotes education and economic diversification breaks the link of direct dependence, reducing vulnerability to external climate shocks.
Adebayo et al. [74]	Vulnerable Communities (Agriculture)	Community adaptation strategies	Social Cohesion: Strengthening community networks acts as a safety net that compensates for the lack of state infrastructure or financial resources.
Gichangi et al. [23]	Semi-arid Zones (Subsistence)	Autonomous adaptation to droughts	Income Disparity: Without external support, management strategies fall on households, eroding up to 50% of their income and perpetuating the cycle of poverty.

A key finding is that the social impacts of climate change are unevenly distributed among social groups. Rural and Indigenous communities, as well as households highly dependent on natural resources, are more exposed to climate risks and have less adaptive capacity due to a lack of access to infrastructure, financing, and social protection systems. Gichangi et al. [23] show that in semi-arid zones, soil degradation and water scarcity can reduce household income by up to 50%, generating cycles of poverty that limit future adaptive capacity. Table 5 confirms that when management strategies rely on autonomous adaptation without institutional support, the economic cost falls on households, increasing inequality and food insecurity. These results align with those of Moser et al. [10], who indicate that mitigation and adaptation policies can generate long-term benefits but produce immediate social costs if local socioeconomic conditions are not taken into account.

A second identified pattern is that strategies based solely on infrastructure or technical solutions tend to generate unequal social outcomes. Kohlitz et al. [27] document that decentralized water harvesting systems can improve water security overall, but also increase inequality when access depends on households' economic capacity to install and maintain the infrastructure. This type of outcome indicates that climate management can reproduce existing inequalities when it is not accompanied by redistributive policies or public support mechanisms. Similarly, Frank et al. [6] point out that allocating climate resources without accountability mechanisms can concentrate the benefits in actors with greater institutional capacity, reducing the positive social impact of the investment.

In contrast, the literature shows that strategies incorporating participatory governance and strengthening social capital generate more sustainable results in terms of community resilience. Baccar et al. [28] demonstrate that collective resource management systems improve coordination, reduce conflict, and facilitate knowledge sharing, thereby increasing communities' actual adaptive capacity. Adebayo et al. [74] show that in vulnerable agricultural communities, strengthening social networks and local organizations acts as a form of informal insurance against extreme weather events, compensating for the lack of state infrastructure. Table 5 reflects that these approaches not only improve access to resources but also increase the legitimacy of environmental policies, thus promoting their long-term sustainability.

Beyond improving participation itself, decentralized governance redistributes decision-making authority to local actors who possess detailed knowledge of ecosystem dynamics and livelihood needs [27,28]. Across the reviewed studies, decentralization appears to enhance social resilience when accompanied by institutional coordination, transparent accountability mechanisms, and equitable access to financial and technical resources [10,27,28]. Under these conditions, community participation facilitates collective learning, strengthens trust among stakeholders, and increases the legitimacy and long-term acceptance of adaptation policies [28,42]. Conversely, decentralization alone does not guarantee equitable outcomes. Where local institutions lack financial capacity or decision-making authority, or where governance processes exclude vulnerable groups, decentralized management may reproduce existing inequalities and reduce the effectiveness of climate adaptation strategies [6,10,27]. Therefore, the reviewed evidence suggests that participatory governance should be understood not simply as an administrative arrangement but as a mechanism that links institutional capacity, social inclusion, and adaptive decision-making within sustainable natural resource management [23,27,28,41,42].

These findings also have direct implications for governance reform and public policy design. Rather than relying exclusively on technical adaptation measures, the reviewed evidence suggests that resilience is strengthened when climate policies incorporate institutional arrangements that promote inclusive decision-making, transparent allocation of climate finance, and coordination among national, regional, and local authorities [6,32,49–51,67]. Policy instruments such as participatory natural resource management, community-based adaptation programs, ecosystem-based management plans, targeted financial support for vulnerable households, and mechanisms for monitoring and accountability are consistently associated with improved adaptive capacity, stronger social cohesion, and more equitable resource governance [6,32,49–51].

Consequently, the reviewed evidence suggests that governance reforms should be considered a central pillar of climate adaptation strategies, ensuring that environmental interventions are supported by inclusive institutions, coordinated policymaking, and equitable access to adaptation resources, thereby enhancing long-term community resilience and sustainable natural resource management [6,32,49–51,67].

Another key finding is that economic diversification and access to education reduce direct dependence on natural resources and, therefore, vulnerability to climate change. Murshed et al. [42] show that strategies promoting productive diversification break the link between income and direct resource exploitation, increasing the structural resilience of communities. This finding is consistent with the evidence presented in the previous questions, which showed that extractive dependence not only increases emissions and economic costs but also limits social adaptation options. In this regard, Table 5 shows that policies focused on human development, education, and alternative income generation have more lasting effects than interventions centered exclusively on production.

The review also highlights the importance of considering gender and climate justice in natural resource management. Several studies show that women play a central role in the day-to-day management of water, soil, and forests, but have less access to decision-making and productive resources. Environmental degradation increases the burden of unpaid work and reduces economic opportunities, limiting households' capacity to adapt. These findings suggest that management policies that do not incorporate equity approaches can reduce the effectiveness of climate strategies, even when they are technically sound [10,42].

A cross-study comparison of the evidence summarized in Table 5 reveals three recurring management pathways with distinct social outcomes. First, strategies based primarily on infrastructure development or technical adaptation measures tend to improve resource availability but often generate unequal benefits when access depends on household income, institutional capacity, or existing social conditions. Second, autonomous adaptation approaches frequently transfer climate risks and adaptation costs to local communities, increasing vulnerability among resource-dependent households. Third, integrated strategies that combine participatory governance, social capital strengthening, education, and productive diversification consistently produce the most favorable outcomes in terms of equity, adaptive capacity, and long-term resilience. Across different geographical contexts, the reviewed studies suggest that social resilience is determined less by the amount of climate investment itself than by the inclusiveness of governance arrangements and the extent to which vulnerable groups participate in decision-making processes.

While the reviewed studies provide substantial evidence regarding the economic, environmental, and social consequences of natural resource management under climate change, the synthesis also revealed important differences in methodological approaches, geographical coverage, and analytical integration. Therefore, the following section distinguishes between empirical findings derived from the literature, limitations affecting current knowledge, and priorities for future research.

Collectively, the evidence suggests that social resilience is not an independent outcome but rather the cumulative result of environmental conditions, economic opportunities, and institutional effectiveness. The reviewed studies consistently indicate that participatory governance, social capital, and inclusive decision-making operate as cross-cutting mechanisms capable of simultaneously reducing vulnerability and improving the effectiveness of adaptation strategies.

3.6. Knowledge Gaps Regarding Natural Resource Management Under Climate Change

3.6.1. Empirical Findings from the Reviewed Literature

The systematic review identified three main empirical patterns regarding natural resource management under climate change. First, the evidence consistently demonstrates that environmental degradation generates interconnected economic, environmental, and social impacts rather than isolated consequences. The reviewed studies show that natural resource degradation is associated with GDP losses, reduction in household income, increased adaptation costs, greenhouse gas emissions, and declining ecosystem resilience.

Second, the evidence indicates that extractive dependence, weak institutional capacity, and limited productive diversification are recurring factors that amplify vulnerability. Across different geographical contexts, studies consistently reported that economies highly dependent on natural resources face greater exposure to climate-related shocks and have lower adaptive capacity.

Third, the reviewed literature shows that adaptation and mitigation strategies are more effective when they integrate environmental conservation, economic diversification, and participatory governance. Evidence from multiple regions suggests that approaches

based exclusively on technological interventions or infrastructure investment may generate limited social benefits if institutional and equity considerations are neglected.

3.6.2. Limitations Identified in the Existing Literature

Despite important advances, the reviewed literature presents several limitations that restrict the generation of integrated conclusions. First, most studies evaluate economic, environmental, and social dimensions separately, limiting the understanding of interactions among natural capital degradation, economic losses, and social vulnerability.

Second, substantial methodological heterogeneity was identified among studies, including differences in indicators, spatial scales, temporal horizons, and valuation approaches. This heterogeneity limits direct comparisons between regions and prevents the establishment of universally applicable thresholds for sustainable natural resource management.

Third, geographical coverage remains uneven, with evidence concentrated in specific regions and ecosystems, while vulnerable areas in developing countries remain comparatively underrepresented. Additionally, many studies rely on short-term assessments, reducing the capacity to evaluate long-term effects of climate adaptation strategies.

Finally, although governance is frequently recognized as an important factor, quantitative assessments linking institutional quality, policy effectiveness, and socioeconomic outcomes remain limited.

3.6.3. Future Research Priorities

Based on the identified gaps, future research should prioritize integrated analytical frameworks capable of simultaneously evaluating economic, environmental, and social outcomes. Longitudinal studies combining ecological indicators, economic valuation, and social vulnerability assessments are needed to better understand cumulative impacts under climate change scenarios. Future research should also improve methodological harmonization by developing standardized indicators that allow comparisons across regions and sectors. Greater attention should be given to developing countries and vulnerable communities, where climate impacts are expected to be more severe but empirical evidence remains limited. Furthermore, interdisciplinary approaches integrating climate science, economics, ecology, and social sciences should be promoted to evaluate not only the effectiveness of adaptation strategies but also their distributional effects and implications for equity. Such efforts would improve the capacity of decision-makers to design policies that simultaneously protect natural capital, reduce economic risks, and strengthen social resilience.

3.7. Integrated Synthesis of the Evidence

Although the results were presented according to four research questions, the evidence synthesized in this review indicates that these dimensions should not be interpreted independently. Across the reviewed studies, a recurrent socio-ecological pathway emerged in which inadequate natural resource management acts as the initial driver connecting environmental degradation, greenhouse gas emissions, economic losses, and reduced social resilience.

The comparative analysis also revealed that similar management failures—including extractive dependence, weak institutional capacity, insufficient adaptation investment, and limited productive diversification—were repeatedly associated with multiple negative outcomes regardless of geographical region or resource type. Rather than representing isolated environmental, economic, or social problems, these findings suggest that climate-related vulnerability results from the interaction of these dimensions within a common socio-ecological system.

Consequently, sustainable natural resource management should be understood as a multidimensional process requiring coordinated environmental protection, economic planning, and inclusive governance instead of sector-specific interventions.

3.8. Limitations of the Review

Several limitations should be acknowledged. First, the literature search was limited to English-language publications indexed in Scopus, potentially excluding relevant evidence from other bibliographic databases, gray literature, and studies published in other languages. Second, despite the application of quality appraisal and risk-of-bias assessment procedures, substantial heterogeneity in study designs, analytical approaches, and outcome measures hindered direct quantitative comparisons across studies. Consequently, the findings should be interpreted in light of these methodological constraints. Future reviews could broaden the scope by incorporating additional databases, non-English publications, and gray literature to provide a more comprehensive assessment of the evidence base and to further validate the trends identified in this review.

Although this review identifies consistent relationships reported across the literature, the evidence synthesis is based primarily on observational and case-based studies. Consequently, the identified associations between governance mechanisms, productive diversification, natural capital management, and resilience outcomes should not be interpreted as causal effects. Further empirical research is required to determine the effectiveness and transferability of specific interventions across different socioeconomic and ecological contexts.

4. Conclusions

Based on the comprehensive analysis developed in this manuscript, it is concluded that the management of natural resources under climate change conditions is a determining factor for economic stability, social resilience, and environmental sustainability. However, its effectiveness depends on the capacity of institutional systems to simultaneously integrate macroeconomic, territorial, and community dimensions. The reviewed evidence shows that the impacts of climate change are not limited to isolated environmental losses, but rather translate into cumulative processes that affect productivity, food security, public finances, and social cohesion, generating systemic risks that can overwhelm the response capacity of states when dependence on natural resources is high.

The results suggest that management models focused exclusively on economic exploitation or partial technological solutions tend to generate counterproductive effects in the long term, especially when they fail to consider the biophysical limits of ecosystems or existing social inequalities. In contrast, approaches that combine productive diversification, institutional strengthening, investment in natural capital, and social participation show a greater capacity to reduce vulnerability to climate shocks and to sustain more stable development trajectories. This indicates that resilience is not solely a result of the availability of financial resources, but rather of the coherence between economic, environmental, and social policies.

However, the heterogeneity of methodologies, indicators, and analytical scales among the reviewed studies prevents the establishment of causal relationships or the generalization of policy effectiveness across contexts. Therefore, the findings should be interpreted as identifying recurrent patterns and potential pathways for improving natural resource management rather than as definitive evidence of intervention impacts. Future research should prioritize longitudinal studies, comparative assessments, and integrated evaluation frameworks to better understand how governance reforms, economic diversification, and natural capital accounting influence long-term resilience under climate change.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/earth7040132/s1>, Table S1: Methodological quality assessment rubric used for study appraisal.

Author Contributions: Conceptualization, F.G.-Á. and J.L.-N.; methodology, F.G.-Á., V.T.-R. and D.S.-C.; software, R.M.-M.; validation, F.G.-Á., J.L.-N., L.V.-G. and I.T.-P.; formal analysis, D.S.-C. and R.M.-M.; investigation, V.T.-R., J.L.-N. and I.T.-P.; resources, L.V.-G.; data curation, R.M.-M. and D.S.-C.; writing—original draft preparation, F.G.-Á. and V.T.-R.; writing—review and editing, J.L.-N., L.V.-G., R.M.-M. and I.T.-P.; visualization, D.S.-C.; supervision, F.G.-Á. and L.V.-G.; project administration, L.V.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This research did not receive external funding. The APC was financed by the Universidad Tecnológica del Perú.

Data Availability Statement: All data extracted and analyzed are duly documented and included in the manuscript. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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