

Annual Review of Environment and Resources
 Characterizing the Global
 Polycrisis: A Systematic Review
 of Recent Literature

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Keywords

multiple crises, cascading, entanglement, challenges, metacrisis, multicrisis

Abstract

The term polycrisis has gained prominence, capturing the interconnected nature of global challenges such as climate change, pandemics, conflicts, and economic instability. Originating in the 1960s, the concept now reflects the growing complexity and interactions among global crises. In this article, we conduct a two-step systematic review of the definitions, components, drivers, and interventions of the polycrisis. After scanning 2,299 publications, we analyzed 59. Coding for definitions and descriptions, we clustered crises, drivers, and interventions. Results indicate a common understanding of the polycrisis as *multiple co-occurring, causally entangled crises with synergistic and cascading effects on multiple systems degrading humanity's prospects*. While crises such as climate change, the human health crisis, and inequality are frequently mentioned, their interactions remain underexplored. Drivers often stem from systemic societal and economic factors, and the proposed interventions emphasize a need for transformational change. Future research should explore causal pathways, identify vulnerabilities, review interventions, and harmonize knowledge systems for action.

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1. INTRODUCTION

Most people have been recently affected by various global crises. Since 2020, the world has experienced the COVID-19 pandemic, many extreme weather events associated with climate change, new and ongoing wars, upheavals in global food markets following the Russian invasion of Ukraine, and rapid political changes in democratic regimes. An increasing understanding that

such global crises are interconnected has led to the (re)adoption of the term polycrisis and to the recent proliferation of scientific publications referring to it (1–4).

The notion of multiple crises occurring simultaneously and interactively, leading to large-scale changes, is not new. It has long been known that multiple factors (crises) simultaneously contributed to the declines of historical empires, but it was not until the Club of Rome scientists applied this to Western civilization with the publication of the “Predicament of Mankind” in 1970 (5–7) that it gained prominence in modern discussions. By listing 49 problems facing humanity, the Club of Rome was first to acknowledge the scope, complexity, and severity of the phenomenon we now call the global polycrisis. Their work sparked the development of the first Earth system models as means to study the interconnections between crises and other global challenges [see the historical overview by Bardi & Pereira (6)]. A more recent but related body of literature refers to humanity surpassing planetary boundaries (8, 9) risks emerging from environmental crises (e.g., 10–12), urbanization (13), and our economic system (e.g., 14–16).

While the polycrisis concept is not new (17), scholarly attention has increased sharply since 2022, with scientists from various disciplines increasingly studying how the various global crises are interconnected (18–22). The term polycrisis provides a new lens for studying the ongoing global crises and their interconnections, as Helleiner (22) proposed. It encourages a deeper and better-integrated analysis than prevailing perspectives from siloed disciplines, which is essential in addressing this complex phenomenon. Grounding the concept into a solid research agenda may also inform strategies to prevent the entanglement of several crises and their amplified impact (21).

Nonetheless, to date, there seems to be little consensus on what the polycrisis is, what its most important component crises are, and how they affect each other. Several authors have provided overviews of the history of the term (18, 22, 23), noting that the term remains a buzzword with little well-defined content (21). These publications showed a variety of approaches to the concept of the polycrisis and disagreement about whether multiple polycrises (e.g., 22, 24) or only one exists (e.g., 21, 25). Similarly, there is no consensus on the characteristics of the polycrisis, the specific crises it encompasses, its key drivers, the regions and groups most affected, and the potential interventions to address it.

Disagreement regarding the polycrisis and its components may hamper the ability to study, understand, and use this concept effectively, as well as to find constructive solutions. To overcome this barrier, we review the most recent research on the global polycrisis, aiming to understand scholars’ current opinions on (a) what defines the polycrisis, (b) what crises comprise it, (c) what are its key drivers, (d) what are the most affected regions and people, and (e) what interventions are being proposed to address it. To this end, we performed a systematic review of the scientific literature dealing with the polycrisis and its synonymous terms. Thereby, we aim to contribute to a more consistent use and understanding of the concept, including its context, drivers, and subcrises, and to identify critical knowledge gaps that can help guide future research. Additionally, we strive to synthesize proposed interventions, thus, contributing to efforts in addressing what is possibly humanity’s greatest challenge.

2. METHODS

2.1. Selection of Relevant Publications

We performed a systematic review of the literature referring to the polycrisis and synonymous terms, following four steps: First, we identified which terminology has been used to describe the same phenomenon. For this, we used the Web of Science (All Databases Search) to find all publications mentioning polycrisis (102 publications on May 20, 2024, excluding three duplicates)

(**Supplemental Figure 1**, including Reference 115). We collected synonyms for the concept of polycrisis from these publications, or from their abstracts when the full text was not accessible (41 terms; see **Supplemental Tables 1 and 2**). The collected synonyms were consolidated and used to identify search terms for the next stage. In this first step, we included English literature and English synonyms only but included literature in other languages in the final search (see below).

In the second step, we harvested all publications that described, explained, or analyzed the global polycrisis. We performed a topic search using all these terms (verbatim) in the Web of Science All Databases Search (June 26, 2024). Because our search included terms that are shared over many languages (e.g., poly, crisis, multi), and since many publications provided English abstracts and keywords, we could include publications in English, Spanish, Chinese, Arabic, Russian, French, German, and Portuguese. This search yielded 2,299 publications (**Supplemental Figure 1**), which we scanned for relevance based on title and abstract. Inclusion criteria were publications (a) covering the polycrisis at a global scale, (b) covering three or more global crises, and (c) analyzing components or drivers of the polycrisis. We excluded publications referring to medical crises, risks, and local or regional polycrisis, as well as publications not analyzing the polycrisis but only using the concept as a buzzword in the introduction or discussion. Three publications could not be retrieved, despite attempts to reach the authors. The final selection of publications is listed in **Supplemental Table 3** (including References 116, 118–120).

As a third step, to consider the growing number of references to the polycrisis not only in academic publications but also in books, we performed a full-text book search using Google Books (performed July 4–5, 2024). To address the search engine's restriction on the number of searchable terms, each of the 41 search terms was queried separately. This allowed us to accurately trace which term was used in the books. For each term, we searched the first 100 hits for relevant books by screening titles and, when necessary, the abstracts. We listed relevant books and removed duplicates. Of the 4,100 book titles screened, we listed 39 books as potentially relevant (**Supplemental Figure 1, Supplemental Table 4**, including Reference 117). Based on the title and abstract, each member of the author team was asked to vote for the 10 books they deemed most relevant. This led to a list of 12 books, of which two books were still excluded after reading (i.e., they lacked a coherent analysis of the crises). For edited volumes with only specific chapters reviewed, each chapter was considered a separate publication.

Lastly, from all selected publications ($n = 59$), we systematically harvested (a) how authors defined or described the polycrisis, (b) which individual crises were considered to comprise the polycrisis, (c) what were listed as its drivers, (d) who were the most affected people or regions, and (e) what potential interventions were proposed by the authors.

2.2. Data Analysis and Integration

For each topic, two to three of the coauthors independently conducted clustering and classification analyses, cross-checking their results with inputs from the others. The entire author team then collaboratively reviewed the results.

2.2.1. Defining the polycrisis. To better understand how various authors understand the polycrisis, we analyzed the definitions and descriptions of the polycrisis, and its synonyms, in the reviewed publications. While not all sources provided a formal definition, many offered comprehensive descriptions that reflect the authors' interpretations of what constitutes a polycrisis. We analyzed these through inductive coding of the relevant sections, where categories and themes are extracted from the text, followed by qualitative clustering into higher-level categories (26, 27). Thereby, we developed a set of mutually exclusive categories of polycrisis characteristics. Finally, we counted the number of publications referencing each characteristic.

2.2.2. Crises comprising the polycrisis. To understand contemporary thinking on which crises comprise the polycrisis, we first harvested the crises listed in each publication. The level of detail used to describe these crises varied broadly, ranging from highly specific events to more general terms such as environmental, social, or political crises (**Table 1**). We therefore grouped the collected crises into broader, nonoverlapping categories of main crises. For instance, mental health crises, pandemics, and chronic or infectious diseases all fell under human health crisis, whereas climate catastrophe, climate crisis, and climate emergency were clustered under climate change. To aid interpretability, we clustered the main crises into one of three primary clusters: environmental, socio-political, or economic. For example, climate change was classified in the environmental cluster, whereas democratic backsliding was classified in the socio-political cluster. When the boundaries between clusters were not clearly delineated, or when crises could fit into more than one cluster, we assigned some crises into a secondary cluster. For example, the governance crisis and the technology crisis were positioned at the intersection of the socio-political and economic cluster, as they contain aspects of each. Similarly, the water crisis (encompassing terms such as water insecurity, water quality, and changes to the global water cycle) was placed at the intersection of the socio-political and environmental cluster, reflecting both environmental changes in the water cycle, and socio-political concerns related to water provision and quality. Many publications mentioned unspecified higher-level crises, such as environmental degradation, social collapse, or political instability, without clear reference to a mechanism. We grouped these under general crises within the corresponding cluster.

Finally, we counted the number of publications listing each main crisis and each cluster, excluding two reviews. If a crisis or a cluster was mentioned in more than 90% of the publications, we took this as evidence of agreement that it contributes to the polycrisis.

2.2.3. Drivers of the polycrisis. To understand what fuels or causes the polycrisis, we harvested all drivers mentioned in the publications. In some cases, the authors did not explicitly use the terms driver or cause, but the texts clearly indicated what they considered to be such. In these cases, we listed the mentioned factors as drivers. The results are therefore referring to all factors that were listed either explicitly or implicitly as drivers.

In the first step of this part of the analysis, we again used inductive coding to group the drivers into a two-level hierarchical classification system, accounting for the varying levels of specificity of the harvested drivers. For example, both agriculture and livestock farming were grouped under the broader category of agrifood systems, with livestock farming as a subcategory. In total, we identified eight broader and 29 specific driver subcategories.

These consolidated drivers fell into two groups: (a) crises acting as drivers (as identified in Section 3.3.) and (b) other drivers (see further reflection in Section 4.3.). For the first group, we categorized drivers using the environmental, socio-political, and economic clusters as broader categories, along with the 24 previously defined main crises. The differentiation in the second group was guided by established driver frameworks, such as the Driver-Pressure-State-Impact-Response (DPSIR) approach (28, 29) and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and Intergovernmental Panel on Climate Change (IPCC) synthesis (30, 31). This process resulted in the identification of five broader driver categories and 19 subcategories.

2.2.4. Most affected regions and social groups. If publications explicitly mentioned or described regions or groups that are (most) affected by the polycrisis, or can be potentially most affected, we collected this information. Spatial information included, for instance, the scale, region, countries, or continents listed. For groups, we noted socio-economic or other identity dimensions, such as gender or age.

Table 1 Description of the main crises based on terms and explanations used in the reviewed literature

Crisis	Description
Climate change	Long-term shifts of weather and temperature patterns due to anthropogenic emissions of greenhouse gasses
Biodiversity loss	A continuous decline in genetic, species, and ecosystem diversity, including the loss of natural habitats and ecosystems
Water crisis	Changes in global, regional, and local water cycles that affect the availability of water in terms of quantity and quality
Resource depletion	The consumption of natural resources at a rate that is higher than natural regeneration, leading to (actual or speculated) scarcity
Pollution	The introduction of harmful substances and contaminants into the environment, which can be chemical, biochemical, or novel entities, as well as light and noise pollutants
Land system crisis	A change of natural vegetation cover that influences the functioning of the biogeophysical system (such as fires, land conversion, or degradation)
Human health crisis	Global threats and insecurities to health and the healthcare system, specifically, mental health, pandemics (frequent references to COVID-19), obesity, and noncommunicable diseases
Conflicts and wars	Physical combat and political maneuvers such as sanctions, diplomatic pressure, or cyber warfare
Inequality	A widening gap in income, wealth, opportunities, and access to resources both within and between societies, social groups, and nations
Food insecurity	Limited or volatile availability of food; encompasses the loss of genetic diversity and market volatility threatening the resilience of food systems and people's capacities to access and obtain healthy diets
Democratic backsliding	An incremental erosion of democratic structures, marked by weakening judicial independence, reducing checks on the executive, restricting fundamental human rights, and undermining electoral integrity
Human rights violations	Systemic and frequent denial or abuse of the rights of individuals or groups by states or individuals, based on race, gender, nationality, ethnicity, language, religion, political affiliation, or any other characteristic
Migration crisis	Difficult or dangerous situations arising from the movements of large groups of displaced people in the receiving states, potentially leading to social unrest
Governance crisis	The dysfunction or inadequacy of institutions in effectively managing and addressing critical societal issues
Crisis of social reproduction	A breakdown or strain of labor that sustains societies through caregiving, education, healthcare, or other forms of (often) unpaid labor supporting households, communities, and institutions
Demographic crisis	Changes in the long-term demographic build-up of the human population, including population growth and decline, aging, changes in birth rates, and rural-urban migration
Financial crisis	The significant disruptions of financial markets and institutions, often triggered by a sharp decline in asset values, leading to the insolvency of financial institutions or other economic sectors; crises such as the 2008 global financial crash or the European sovereign debt crisis severely disrupted economic activities across countries
Energy crisis	A disruption in the availability, affordability, or stability of energy resources, often characterized by energy price shocks and volatility in global energy markets
Crisis of global capitalism	Often referred to as a systemic or structural crisis of global capitalism and neoliberal globalization, characterized by financial dominance, market liberalization, and weakened labor power to sustain patterns of capital accumulation
Technology crisis	A critical disruption or failure of systems stemming from technological advancements and their associated impacts, including unforeseen consequences of technological change, as well as so-called technological problem shifting, where solutions to one technological issue inadvertently generate new problems
Crisis of meaning	An existential challenge of finding purpose and significance in life, e.g., reflected in overconsumption and the general diminishing trust in growth-driven paradigms, science, and shared sensemaking

2.2.5. Proposed interventions to address the polycrisis. To identify proposed interventions for addressing the polycrisis, we extracted each recommendation, identified associated actors, and noted whether trade-offs were considered. Using an inductive coding approach, we categorized these, allowing for overlaps of categories to capture the diversity of interventions. For example, One Health and transdisciplinary, transgressive and transcendent approaches were grouped as integrative approaches, while reconnect with nature and shift to a new paradigm were categorized as address societal values, norms and habits.

Following Meadows' (32) framework of leverage points for transformational system change, we used Abson et al.'s (33) adaptation to classify the harvested interventions into four levels of system characteristics: intent, design, feedback, and parameters characteristics, ordered from deep to shallow. Each characteristic aggregates several of Meadows' (32) leverage points, illustrating different ways to intervene in systems. Intent reflects the norms, values, goals, and underlying paradigms that guide a system's emergent direction. Design pertains to the structure of information flows, rules, power dynamics, and mechanisms for self-organization. Feedbacks refer to the interactions among elements within a system that shape its internal dynamics. Parameters are relatively mechanistic characteristics (taxes, incentives, and standards) that are usually targeted by policymakers (33). For example, the interventions harvested from the literature that modify existing economic and governmental systems could be classified at the levels of parameters, feedback, or design, depending on the nature of the proposed change. In contrast, interventions advocating for a fundamental redesign of these systems (e.g., shifting from a growth-based to a steady-state economy) were classified under intent. For further explanation, see Abson et al. (33).

3. RESULTS

Using 41 synonyms for polycrisis (**Supplemental Tables 1 and 2**), our systematic literature search yielded 49 scientific publications and 10 books, totaling 59 publications fitting our criteria (57 in English, 1 in Portuguese, 1 in French). The main reasons for excluding 106 publications after full-text screening were the use of polycrisis as a buzzword [45], a narrow focus on fewer than three crises [33], and/or limited scale [35]. Although the specific term polycrisis was first coined in 1999 (17), the earliest scientific publication picked up by our search was from 2010, and three-quarters of the publications have been published between 2022 and our search dates (June 2024) (**Figure 1a**). The earliest articles (34, 35) had a clear focus on the 2008 financial crisis, but several authors mentioned other concurring crises, using terms such as multiple crises, converging crises, and plural crises, which included climate change, food insecurity, and the ecological crisis. The term polycrisis was revived in 2016 by J.-C. Juncker (1), then president of the European Commission, to describe the cluster of the 2015 refugee crisis, Brexit, continuing financial crises, and rising geopolitical tensions as applied to the European Union context. In January 2023, it was popularized by the World Economic Forum annual risk report (4), after which the use of the term increased sharply. For a more detailed historical overview, see Matlovic & Matlovičová (18) and Lawrence et al. (21). Apart from a brief critique of the term by Lawrence et al. (21), challenging the novelty of the current global state and its potential association with capitalist, elite perspectives, we found no substantial or fundamental criticism in the reviewed publications.

Most publications used a narrative approach to describe the interactions between crises, and only a handful used conceptual mapping to describe this interconnectedness (21, 36). Only one publication (15) is based on a system dynamics modeling approach, based on models by Randers & Collste (37). The publication by Lawrence et al. (21) stands out in concentrating on a systemic understanding of the polycrisis rather than on the crises comprising it, while Jørgensen et al. (38)

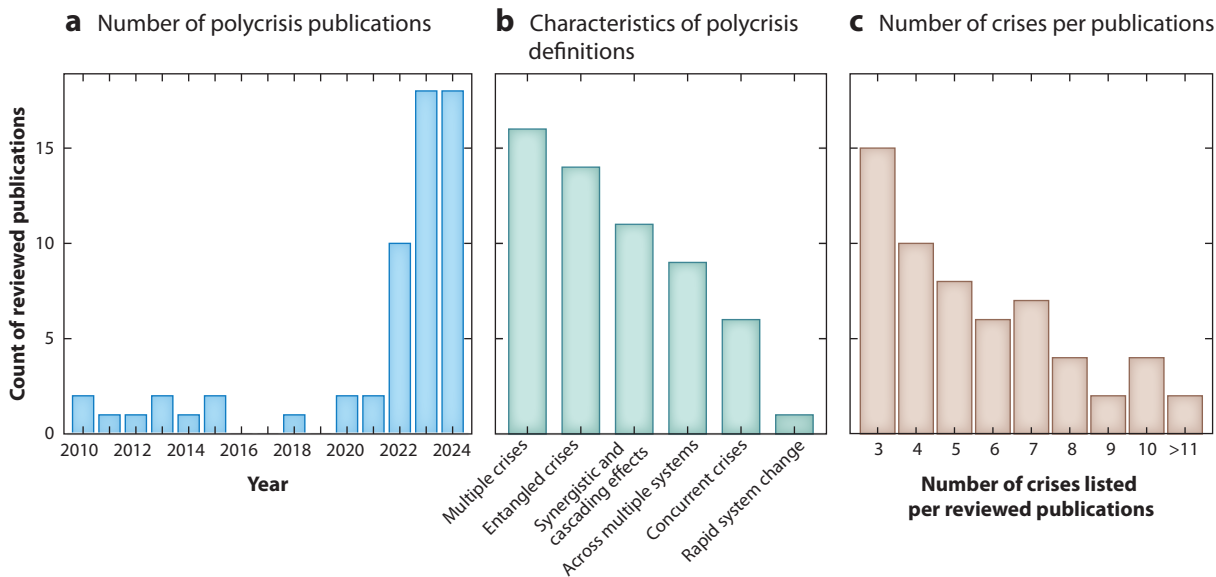


Figure 1

(a) Number of publications covering polycrisis and its synonyms (per year), (b) identified characteristics used in polycrisis definitions or descriptions, and (c) frequency of the number of crises listed per reviewed publication. These counts are based on 59 publications (10 books and 49 peer reviewed publications) found through a systematic literature search performed between May and July 2024 using Web of Science and Google Books. There was no restriction on publication dates and the oldest publication found was from 2013.

takes a different perspective by focusing on trajectories leading to crises, including lock-ins, which they define as anthropocentric traps.

A non-negligible part of the literature (at least 11 publications) expressed views that could be regarded as anticapitalist, antiglobalist, or (Neo)Marxist (e.g., 25, 34–36, 39–45). Several of these publications referred to a general crisis of capitalism. We could not identify any publications coming from a clear libertarian or capitalist worldview.

3.1. Defining the Polycrisis

We found 22 publications containing definitions or descriptions of the polycrisis (**Figure 1b**). We identified several consistent characteristics of the polycrisis as described over time.

First, multiple crises occur simultaneously, as reflected in 16 out of 22 descriptions (e.g., 21, 34, 36). However, only six definitions were explicit about simultaneity, using terms such as concurrent crises (e.g., 46, 47).

A second characteristic is the interdependence and interactions between crises, blurring the boundaries between individual crises. This is reflected in the term entangled crises (e.g., 18, 48, 49), used in 14 of the descriptions. The property of entanglement has been consistently noted since 2010 (34), with some definitions since 2022 introducing causally entangled crises to emphasize the causal interlinkages (e.g., 21, 50, 51).

A third characteristic is synergistic and cascading effects (11 descriptions, since 2022), referring to the combined impact exceeding the sum of the individual crises, often triggering new crises (e.g., 24, 51, 52). Synergistic effects describe the mutual amplification of different crises and feedback loops, and cascading effects refer to the chain reactions across interconnected systems, resulting in widespread and intensified outcomes. Several publications further elaborated on the impacts

and outcomes of the polycrisis. For instance, Taehtinen et al. (49) and Matlovic & Matlovičová (18) emphasized that the polycrisis disrupts multiple aspects of society, whereas others focused on the implications for policymaking (21, 24, 51), building on the work of Davies & Hobson (53). These authors underscored the complexity and challenges inherent in addressing the polycrisis, particularly how efforts to resolve one crisis within the polycrisis can conflict with or impede the resolution of another. Taehtinen et al. (49) refer to the boundaries and casualties of entangled crises becoming more blurred. Other definitions explored more specific outcomes of the polycrisis. These include the aggravation of poverty and inequality (54), shifts in Earth state and “destruction of existing balances” (39, p. 1), degradation of humanity’s prospect (20, 25), and the collapse of global sustainability (18).

Fourth, recent publications described the polycrisis as being either embedded in multiple systems (21, 50, 51) or acting across multiple systems (18, 22, 44), including temporal and spatial dimensions. Publications since 2024 also referred to systemic vulnerabilities that emerge from these impacts of the polycrisis (e.g., 21, 22, 39, 49, 54, 55) and proposed that, consequently, the polycrisis drives a rapid system change in Earth’s states toward instability and chaos.

Several definitions have been particularly influential: The definitions by Lawrence et al. (20) and Tooze (3) have been quoted or referred to in many publications (e.g., 21, 49, 51, 55). The far-reaching implications of the polycrisis with effects exceeding the sum of their parts and leading to a “[degradation] of humanity’s prospects” is a notable feature of Lawrence et al.’s (20, p. 2) definition.

Based on the above, we describe the global polycrisis as *multiple co-occurring, causally entangled crises with synergistic effects on multiple systems that exceed the sum of its parts and degrade humanity’s prospects*.

3.2. Crises Comprising the Polycrisis

We identified 24 main crises (**Table 1**), grouped into three primary clusters (**Figures 1c** and **2a**). Four of these were also assigned to a secondary cluster (**Figure 2b**). There was strong agreement that crises from both the socio-political and environmental clusters contribute to the polycrisis: All reviewed publications (59 out of 59) listed crises in the socio-political cluster, and 95% (57 out of 59) included crises from the environmental cluster. Additionally, 72% of the reviewed publications (43 out of 59) included crises in the economic cluster. Among the identified crises, two stood out (**Figure 2a**): Climate change was most frequently mentioned in 51 publications (85%), followed by the human health crises, mentioned in various forms (e.g., pandemics, mental health crisis) in 41 publications (68%). Conflicts and wars, along with inequality, followed with 26 (43%) and 28 (46%) mentions, respectively. A financial crisis was highlighted in 19 publications (32%), and democratic backsliding was noted in 16 publications (27%). One publication mentioned the possibility of newly emerging crises of unknown nature (49).

Specific crises were often mentioned in the years following specific events: the 2008 financial crisis (34), COVID-19 (e.g., 40, 56), rising tensions between the United States and China (22), and the Russian invasion of Ukraine and its effects on global food markets (57, 58). Accordingly, we can anticipate the geopolitical upheaval sparked by the new US presidential administration becoming prominent in the coming years.

3.3. Drivers of the Polycrisis

We found 30 publications mentioning causes or drivers of the polycrisis. These ranged from broad and conceptual (e.g., growth economy) to specific sectors (e.g., agriculture) or even parts of a sector, such as livestock farming. In most cases, the literature lacked an analysis of mechanisms and

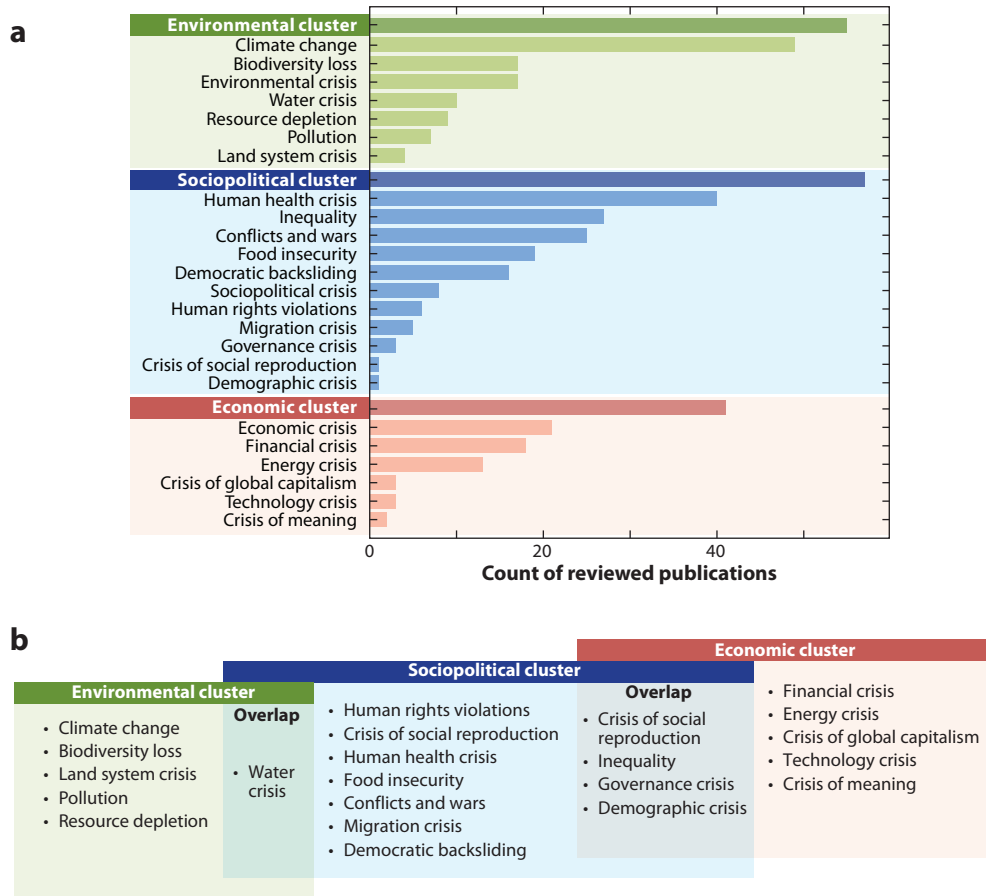


Figure 2

(a) Number of publications listing the different main crises, grouped by their primary clusters, where the darker bars represent the total number of publications listing one or more crises in that cluster. (b) Overlap in clustering of some of the crises. Each main crisis was assigned to a primary, and if applicable to a secondary, cluster. In panel *a* the crises are only grouped by their primary cluster, and in panel *b* the crises with differing primary and secondary clusters are shown in the overlapping areas between cluster boxes.

causal pathways, through which these drivers affect the polycrisis or individual crises comprising it. We distinguished two major groups.

The first group of drivers was identified as crises in other publications (see Section 3.2.). Crises that act as drivers covered all three previously defined clusters (i.e., environmental, socio-political, and economic), including the most frequently mentioned: inequality (e.g., 14–16, 21, 58), conflicts and wars (e.g., 57, 59), the human health crisis (60), the demographic crisis (50), climate change (e.g., 16, 41, 61), resource depletion (14, 57), pollution (60, 62), and biodiversity loss (15, 60). The second group of drivers fell into five broad categories: the prevailing economic system (mentioned by far most frequently), the prevailing norms and values, the agrifood system, land use (change), and overconsumption.

The prevailing economic system was described using terms such as neoliberalism (34, 39, 43, 63, 64), debts (14), and excessive economic growth (e.g., 16, 65, 66). The main reason, the authors asserted, was that capitalism relies on constant economic growth and thus ever-increasing

consumption (16, 66), leading to the expansion of resource use (land, materials, energy; see, e.g., 34, 40, 42, 67). Furthermore, some authors pointed at capitalism demanding free care and reproductive work (67, 68). Others pointed out that economic growth disregards Earth's finite resources (15) and neglects associated negative externalities (35). The prevailing economic system is also tightly linked to both capital and wealth accumulation, thus contributing to rising inequality (34, 35, 40, 65).

Societal norms and values were also frequently listed as driving the polycrisis, using terms such as neoliberal ideology (43), ontological individualism (25), and short-termism (15). Value-related drivers listed by the authors also referred to humanity's increasing alienation from nature (25, 35, 65, 69), resulting in the lack of appreciation for care and reproductive work (67, 68). Some authors asserted that the interplay of the value-related drivers and the prevalent economic system lead to ever-increasing resource exploitation and consumption, coupled with the exploitation of labor to increasing economic inequality, human rights violations, and conflicts (39, 43, 69).

Agrifood systems were frequently cited as a driver, through land conversions, intensive land use, and diets (e.g., 60, 64, 70). Authors often listed more specific practices, including the expansion of livestock farming (70), biofuels and cash crops (64), and industrial crops such as palm oil (15, 45, 60), as well as pesticide use and resource-intensive crop cultivation (e.g., 70).

A closely linked driver was land use and land use change (e.g., 15, 40). Anthropogenic land use directly contributes to the destruction of natural habitats (e.g., for infrastructure, agriculture, forestry, or mining) and therefore to biodiversity loss and the land system crisis. Indirectly, land use is at the root of many conflicts and human rights violations, where economic interests prevail over nature and Indigenous rights (40). Land use, land use change, and the agrifood systems were indicated as all contributing to individual crises, such as those associated with health [e.g., through pollution and zoonoses (42, 57, 61, 67)], climate change [e.g., through destruction of carbon sinks, methane emissions by livestock, and energy-intensive practices (45, 60, 64, 70)], and food insecurity, conflicts, resource depletion, and the water crisis [e.g., through land degradation and overexploitation, and the water crisis (45, 70)].

Finally, overconsumption was frequently mentioned as a driver of the polycrisis (e.g., 34, 39, 40, 45, 50, 71, 72). It was described by authors as unsustainable resource and energy use (39, 50, 66), driven by an expanding consumer population (16, 39, 71). However, most papers do not define overconsumption and only refer to its consequences. Overconsumption can contribute to the polycrisis by driving resource depletion and negative externalities of increased resource extraction—leading *inter alia* to pollution, increased greenhouse gas emissions, and land clearance (39, 71, 72). It was also described in association with inequality, as the more affluent countries and social groups consume more resources than others (34, 39, 50). Jackson & Jensen (72) connect overconsumption to an epistemic “crisis of meaning,” arguing that as long as people seek meaning through the consumption of goods, it will remain impossible to reduce global resource use without addressing this underlying crisis.

3.4. Most Affected Regions and Social Groups

Ten publications specified regions and social groups that are currently most affected by the polycrisis, and five mentioned future regions that are likely to be most affected. None of these contained an in-depth analysis. The regions mentioned as most affected by the polycrisis at present were countries of the Global South (73, 74), low(er)-income countries, countries with less power to negotiate for themselves in the global arena (55, 64), countries suffering from historic social inequality and systemic inequities [the “majority world” (16)], and African countries in general (14, 40, 63). These same regions will likely be most affected in the future (14, 74), in addition to less

resilient regions or those with little capacity to adapt (16, 46). Kovalchuk et al. (57) mentioned countries dependent on food exports from Ukraine.

As the most affected social groups, authors proposed that the polycrisis disproportionately affects poor and low-income groups (16, 47, 55, 75), Indigenous communities (74), women, children, and young adults (14, 46, 55, 68), as well as marginalized and discriminated groups based on gender, sexual orientation, or intersectional identities (55). Communities depending on natural resources, rural communities (14), and those already suffering from food insecurity (57) were also proposed to be severely impacted. Delina (16) stressed the potentially increasing fragility of regions and groups that are already affected by one or multiple crises, through the intersection of social, economic, and geopolitical pressures in the future.

3.5. Interventions to Address the Polycrisis

We found 32 publications that proposed interventions to address the polycrisis, ranging from very general and conceptual to highly specific in terms of actions and sectors. We identified 91 specific interventions, which we clustered into 17 intervention types (Figure 3, Supplemental Table 5). Although they were often linked to specific crises mentioned in the reviewed publications, there was little information about their anticipated impact or impact mechanism, as most publications focused on characterizing the polycrisis rather than proposing (or analyzing) actionable interventions. The question of who could implement these interventions was addressed in only 11 publications, highlighting a diverse range of actor groups, including international

Supplemental Material >

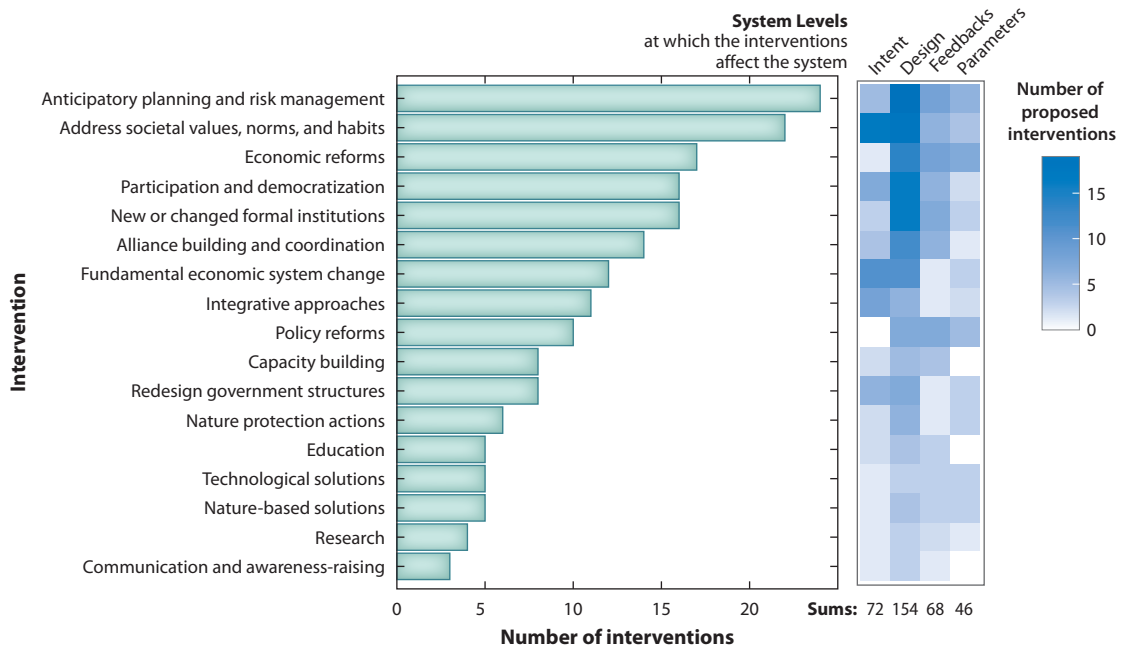


Figure 3

Number of mentioned interventions per category, and per characteristic system levels at which each intervention category intends to affect the system. These characteristic system levels after Abson et al. (33) represent the levels in any system at which interventions can take place. Intent: norms, values, goals, and underlying paradigms that guide a system's direction. Design: the structure of information flows, rules, power dynamics, and mechanisms for self-organization. Feedbacks: interactions among elements within a system that shape its internal dynamics. Parameters: mechanistic characteristics that can be adjusted by policy.

organizations, civil society, private entities, and governments across various levels, without a clear focus on any single group. However, many stressed the need for multi-actor collaboration across sectors, governments, businesses, and multilateral organizations. Only five publications covered trade-offs where interventions may result in adverse effects on nontargeted crises within the polycrisis.

Most interventions focused on generalized strategies targeting certain crises or drivers. These included interventions we clustered under anticipatory planning and risk management and integrative approaches fostering proactive, comprehensive, and coordinated actions to address the polycrisis. Interventions listed under alliance building and cooperation highlighted the importance of aligned efforts and strategies to maximize the impact of the interventions taken. Several interventions focused on the inappropriateness of existing policies, political structures and government systems to address the polycrisis, with interactions focusing on policy reforms, new or changed formal institutions, and redesigning government structures. Additionally, interventions listed under research, education, and capacity building focused on producing and distributing knowledge and skills.

Other interventions focused on changes of the prevailing growth-oriented economic system identified above as one of the key drivers of the polycrisis. Among these, economic reforms focused on introducing both incremental changes [such as prioritizing sustainable funding practices (76)] and redesign and restructuring measures within the existing economic framework [e.g., debt relief and financial reforms for developing countries (14)], those under the “fundamental economic system change,” challenged the assumptions and legitimacy of the growth economy, advocating for a transformative overhaul (for more details, see **Supplemental Table 5**).

Interventions addressing societal values, norms, and habits are directly linked to the value-related drivers, mainly focusing on human–nature relationships and their valuation. They question the principles on which current societies are organized, including the ways in which political systems are justified, legitimized, and structured, and how economic systems are designed. Notably, authors frequently proposed transformational system changes in terms of both the economic system and societal norms and values, emphasizing their mutual interactions. Within this context, addressing (over)consumption was mentioned across all three intervention categories: economic reforms, fundamental economic system change, and addressing societal values, norms, and habits. Interventions addressing the agrifood system often proposed specific production-oriented actions, such as agroforestry (73). Broader approaches targeting the entire food chain were less frequent. Interventions listed under nature protection actions can be linked to addressing land use and land use change drivers.

Among the four system characteristic levels (33), the largest number of interventions belonged to the design level [154], followed by the intent level [72] (**Figure 3**). Most of these interventions proposed profound and far-reaching societal and governmental changes. For example, interventions at the intent level called for no less than a global revolution toward a socialist governance (34, 35, 45, 72), promoting degrowth (66), or proposing a fundamental transformation of human–nature relationships by integrating social justice with environmental sustainability (14). Interventions at the design level included redesigning (global) governance structures (47, 71), enhancing robustness of existing institutions (41, 76), building resilience into agrifood systems (59, 77), and inclusive approaches for eco-social strategies (69). Among the interventions at the feedback level [68] were better regulations for global financial institutions (76, 78), learning, and preparedness in institutions (51). The number of interventions at the parameter level was the smallest [46]: for example, crop diversification (73), technological advances for precision farming (70), or removal of the GDP as the key economic metric (15).

Supplemental Material >

4. DISCUSSION

Our systematic literature review reveals a rapid increase in publications focusing on the polycrisis, in particular, since 2022 (**Figure 1**). Although several publications mentioned this concept as a buzzword, a substantial body of literature seriously deals with the polycrisis and its components, connections, drivers, and possible interventions. This literature is embedded within a broader literature body addressing humanity's future. Several frameworks have been proposed to identify key challenges and responses to the crises faced by humanity, such as planetary boundaries (8, 9), global risk mapping (e.g., 4), and solution-oriented approaches like the UN's Sustainable Development Goals, doughnut economics (79), degrowth, and postgrowth. Yet, this vast body of literature was overall poorly incorporated in the publications we reviewed. This indicates much potential for integration, especially between environmental, socio-political, and economic perspectives on the polycrisis.

In the following sections, we first reflect systematically on our five research questions, identifying recurring themes, inconsistencies, and gaps, while situating our contributions within the scholarly discourse going beyond the polycrisis. We then discuss the broader implications of our results for policy and society, discuss key limitations, and suggest directions for further research.

4.1. Defining the Polycrisis

Some recent publications have explored the development of polycrisis definitions, identifying congruent trends in their use of key characteristics, although without following a systematic approach. For instance, Dinan et al. (51), building on Davies & Hobson (53), highlighted such characteristics as simultaneity, feedback loops, amplification, and unboundedness. Similarly, Matlovic & Matlovičová (18) provided an overview of peer-reviewed and gray literature, outlining comparable definitions and characteristics. Many publications derive their understanding of the polycrisis from a historical perspective, referring to foundational works of Morin & Kern (17) or Swilling (80). This perspective found its relevance in policy contexts and gray literature influenced by such figures as J.-C. Juncker (1) and Tooze (3). Definitions rooted in risk and systems research [such as those by Lawrence et al. (20, 21)], broadened the concept by emphasizing the interaction and interdependence among crises.

Although our results highlight a relatively robust definition of the polycrisis, some characteristics, such as synergistic and cascading effects (e.g., 20, 21, 24, 51), and crises acting across multiple systems (e.g., 21, 50, 51), have only recently been emphasized. These developments, in our view, represent progress in understanding the complexity and severity of the polycrisis. The synthetic polycrisis definition (see Section 3.1.) incorporates this evolving understanding to support the development of consistent terminology and to advance further inter- and transdisciplinary work.

4.2. Crises Comprising the Polycrisis

We found high variability among publications in their inclusion of specific crises in the polycrisis. Most agree on the existence of both an environmental crisis and a socio-political crisis, most frequently mentioning climate change and the human health crisis. However, many merely list crises without exploring interactions between them, leaving these implicit.

The harvested crises span a broad range, from unspecified environmental or political crises to very specific ones, such as a crisis of social reproduction. These results indicate multiple understandings of the word crisis, where it may refer to anything between a sudden catastrophic event (e.g., 49, 81) to an ongoing, slowly unfolding phenomenon (20, 21). Most crises we found in the literature, such as climate change, resource depletion, or inequality, belong to the latter category, highlighting that gradual processes can escalate into catastrophic incidents when tipping points

are reached (49). We found a clear shift over time in the mentioned crises. This can indicate the dynamic nature of the polycrisis and its components but can also result from reactions to recent events—a psychological phenomenon known as availability heuristics or recency bias (82).

Comparing the crises we harvested to the 49 ongoing problems faced by humanity listed by the Club of Rome already in the 1970s—the so-called predicament of mankind—we observe that many of the currently listed crises were listed already then as were, for example, inequality, wars, poverty, and environmental deterioration. The Club of Rome also highlighted important mechanisms driving the phenomenon we now call polycrisis, such as socio-political polarization, misinformation, and the effects of technological progress. Only a few recent studies referred to the Club of Rome (5, 7) or mentioned these mechanisms. Thus, issues raised more than 50 years ago remain poorly addressed, both in society and science. However, there are also some big differences between contemporary literature and the Club of Rome: Climate change, which now tops the list of the most frequently mentioned crises, was not mentioned in 1972 (7). Other environmental problems also became much more prominent, namely biodiversity loss, the water crisis, and the land system crisis, likely reflecting both their accelerating nature and improved scientific understanding (10, 83, 84). Among the newly mentioned socio-political and economic clusters, democratic backsliding, migration, financial instability, and the energy crisis originate from recent socio-political developments, including armed conflicts (e.g., in the Middle East, or the Russian invasion of Ukraine) or the rise of right-wing populists (e.g., in the United States, Brazil, and Hungary). This may be an indication of the dynamic nature of the polycrisis, where new crises emerge that interact with previous and existing crises, with possible cascading effects *sensu* Lawrence et al. (20, 21) and IPBES (84).

Some crises were rarely mentioned, which may not mean that they're lacking in importance but, rather, that they are less explored and may hence warrant further attention. For example, the water crisis was infrequently mentioned in the literature, although IPBES (84) identifies it as one of the key parts of their environmental crisis nexus (see also 85). Only a few recent publications refer to the technology crisis, mostly referring to digitalization and artificial intelligence (AI). Given the rapid developments in this arena and their potential global effects (86), we expect more frequent mentions of AI in the future, as a driver or as a crisis. Among the rarely mentioned crises—yet historically not new—are also the crises of global capitalism, of meaning, and of social reproduction. These deep systemic crises may reflect a depth of analysis that few authors share but may also reflect the presence of (Neo)Marxist perspectives in the reviewed publications.

4.3. Drivers of the Polycrisis

Working through the results on factors driving the polycrisis, two major observations stand out. One is that some crises act also as drivers of the polycrisis. This demonstrates the causal entanglement among crises, by which one crisis aggravates the other, directly or indirectly. Such entanglement was shown, for instance, by Creutzig et al. (87), who describe gender and income equality, social trust, and climate policy as entangled in a causal loop. Among the crises mentioned as drivers are climate change, biodiversity loss, conflicts and wars, and inequality (see Section 3.3.). Secondly, several systemic factors are mentioned as ultimate drivers, including the economic system, societal values, the agrifood system, land use (especially, land-use change), and overconsumption. These ultimate drivers largely align with major global scientific reports on individual crises (e.g., 10, 11, 30, 83, 84).

We see two major knowledge gaps in work on the drivers of the polycrisis. Firstly, in most publications, the stated drivers are derived more from authors' interpretations rather than from systematic analyses. Consequently, we could not evaluate the relative importance of the different

drivers and the underlying mechanisms by which they operate on the individual crises or the polycrisis as a whole. For example, the effects of a financial crisis on other crises are rarely mentioned but can have far-reaching consequences (88–90). Similarly, the health crisis has not only short-term impacts on human well-being but also, potentially, long-term rippling effects on economic performance or even socio-political structures, but these are little explored in the literature.

The entanglement of crises and synergistic and cascading effects of the polycrisis are thus well agreed upon (see Section 3.1.) but rarely investigated. There is also a potential for mitigating effects of crises on other crises. For example, COVID-19 led to a sharp but temporary reduction of greenhouse gas emissions (91) and a return of wildlife (92). To add complexity, crises may have indirect effects on other crises through their joint drivers, or on themselves through feedback loops. For example, inequality shapes access to affordable food, influencing dietary patterns and indirectly driving the structure and dynamics of agrifood systems. Our results show that this causal complexity remains poorly documented and quantified, with the exception of Dixon-Declève et al. (15) and the recently published IPBES assessment (84), whose findings largely align with ours.

Another knowledge gap concerns the ways in which drivers operate and potentially interact. Whereas some interactions are known and explicitly mentioned by authors, for example, among our economic system, societal norms, and overconsumption (e.g., 14, 16, 72), the underlying mechanisms of other drivers, such as land use or the agrifood system, remain unclear in the polycrisis context, despite being explored in other contexts (e.g., 93, 94). Importantly, neither the interactions among crises nor their impacts are likely to be static. Rather, they change over time, space, and context (e.g., 21, 84). This dynamic nature challenges attempts to map specific drivers using existing typologies of drivers, such as the DPSIR-framework (28), or distinctions between direct and indirect or proximate and ultimate drivers (as used by IPBES and IPCC). Although such frameworks may work in understanding drivers of individual crises, we found them less suitable in cases where crises themselves act as drivers, or where a driver might directly impact one crisis while indirectly influencing another. Lawrence et al. (21) attempted to address this challenge by introducing the terms triggers for fast-moving events and stresses for slow-moving events. This framework offers a promising approach for advancing our understanding of polycrisis dynamics, especially in combination with dynamic system modeling (15, 37).

4.4. Most Affected Regions and Social Groups

The few publications that made statements on the most affected groups or regions attest that marginalized and vulnerable groups are disproportionately affected by the polycrisis. Most affected people are limited in their capacities to prevent, mitigate, and adapt (16). However, other relevant resources, such as fresh water, energy, access to land, sufficient know-how, and effective governance, likely influence the degree of affectedness of specific regions, social groups, and individuals. Further influencing factors may be population density and mobility (as seen in the case of COVID-19), the spatial distribution of wars and conflicts, or societal responses to human migration. Altogether, it is unlikely that any person will remain unaffected by the unfolding polycrisis, including those in high-income countries or of high socioeconomic status.

However, to our knowledge, no study has so far systematically mapped or quantified the potential impacts of the interacting crises on specific regions and people. Spatially explicit scenario modeling and systems modeling offer tools to explore some dynamics and mechanisms, further providing insights into potential future impacts and informing targeted interventions—but much work is needed to inform, further develop, and parameterize such models.

4.5. Interventions to Address the Polycrisis

Most of the proposed interventions focused on changing people's norms and values and the economic system to combat the polycrisis, aligning with the identified key ultimate drivers. This would address deeper underlying societal structures, aligning with Abson et al.'s (33) design and intent system characteristics. Holistic approaches, such as paradigm shifts and systems-based strategies, were highlighted as ways to tackle multiple crises simultaneously, resonating with literature on transformative change (11, 83) and just transitions (95, 96).

Other interventions such as education, research, communication, as well as technological, nature-based solutions and nature protection were rarely mentioned. This may have various reasons: First, they might be implicitly taken for granted when thinking about system reforms; second, they might be seen as not concrete or effective enough in addressing the polycrisis or its component crises, compared to more effective interventions such as regulations or binding international agreements (97). Third, the reviewed publications may not have adequately considered these interventions; moreover, the literature may exhibit a bias toward economic and political ideas. Although these interventions were infrequently mentioned in the reviewed literature, current policy responses tend to prioritize education and technological solutions as central means to address specific crises (98–101).

This persistent focus on parameter-level interventions rather than on systemic changes (intent or design level) reveals a mismatch between the interventions proposed in the literature and the political practice. Such a bias in the choices made by policymakers has already been highlighted in the contexts of various crises (102, 103). Examples of parameter-level interventions include energy and material efficiency policies (104), food accessibility initiatives, and first-generation biofuels, each of which has led to unintended consequences at systemic scales (105, 106). These examples and others demonstrate a risk in prioritizing parameter-level interventions to address isolated system components, while failing to address cross-system feedback and drivers. The key risk in siloed solutions for individual crises is to perpetuate systemic vulnerabilities while failing to tackle the polycrisis as a whole (84, 107–109). By contrast, transformative approaches advocate for fundamentally redesigning entire systems, such as transitioning to a circular economy that imposes absolute resource constraints (110) or restructuring food systems along agroecological principles supporting environmental and social sustainability (111).

That said, the overall number of publications suggesting interventions was limited (see Section 3.5.) and often lacked concrete actions, detailed analyses of trade-offs, and defined actors. How the proposed interventions may achieve their intended outcomes was often vague or only partially explained, and systemic analyses were rare. Such assessments are gradually emerging for specific crises, as exemplified by Creutzig et al. (112) for climate change and IPBES (84) for the nexus among climate, biodiversity, water, food, and health. Finally, we see a knowledge gap regarding responsibility, i.e., which actors should implement which interventions, under consideration of factors and actors opposing transformation, and those actively pushing in the opposite direction.

4.6. Limitations

Our systematic review focused exclusively on the polycrisis at a global scale and using scholarly literature. National or regional studies will further refine the insights on the context-specific impacts of the polycrisis and its shifting dynamics across the globe. Gray literature, web pages, and research into catastrophic events or future risks may offer additional insights into mechanisms, interactions, and emerging crises.

In our attempts to code and to cluster definitions, crises, drivers, and interventions, we noted that any approach is inherently subjective and is potentially biased by the authors' expertise.

Although we believe that these interpretations are unlikely to have significantly affected the polycrisis definitions and characteristics or the list of crises, we found the drivers to be particularly challenging to define and cluster. The complexity of crises-relations and their drivers requires further research, including conceptual, empirical, and model- (simulation-)based methods.

Regarding the interventions we harvested, we found that there was a mismatch between the global scale of the literature, and the national or regional scale at which interventions are designed and implemented. Identifying and synthesizing interventions will require a broader selection of literature than used for this review.

5. CONCLUSION

The word polycrisis has gained massive popularity since 2022. It is now evident that global crises are interdependent and reinforce each other, and that concerted efforts are necessary to understand this entanglement and how to address it. The polycrisis, understood as “multiple co-occurring, causally entangled crises with synergistic and cascading effects on multiple systems degrading humanity’s prospects,” presents an existential threat to billions of people and to non-human life, and hence the stakes of inaction are immense. With the Club of Rome alerting to these risks more than 50 years ago, it is worrisome that we still have limited understanding of the dynamics, drivers, and key actors of the polycrisis.

The societal and political implications are manifold. The current combination of environmental, socio-political, and economic crises cannot be addressed using the usual siloed responses focusing on one crisis at a time. Instead, it will require a coordinated response to address the polycrisis in its entirety. Lawrence et al. (21) proposed that we (a) focus on crisis interactions, (b) concentrate on system architecture, and (c) exploit high-leverage intervention points. Our work highlights where we might find these leverage points to achieve sufficient progress: in the economic systems, in norms and values, and in how both drive consumption patterns. Critically, these include solutions at both the supply side and demand side of the economy and encompass targeted reforms of institutions, governance, and finances with more specific interventions.

The body of literature we reviewed agrees that addressing the polycrisis will require a holistic approach and transformative changes. Siloed approaches focusing on individual crises are insufficient (84); instead, it requires a fundamental shift in our societal norms and values and economic paradigms. To support this transition, greater investment should be directed toward developing and testing alternative economic and governance arrangements, as well as advancing research on systemic and sustainability transitions including holistic approaches such as agroecology. This will include a monumental effort to overcome habits, traditions, and entrenched power structures of actors with vested interests as well as a shift away from the predominant economic growth paradigm. As flagged by modern sustainability discourse, the transition should follow key principles of justice (14, 16, 113), so that humanity is not being reduced to those in power and with the most resources.

At the same time, societies will need to be better prepared for upcoming shocks and crises to come, as well as their cascading effects. This will require increased resilience, anticipatory planning, and risk management, including financial resources to support the most affected people and regions. Critically, rapid responses to immediate crises should align with long-term transformations toward a resilient, sustainable Earth system to prevent unintended negative effects on other crises. Failures in doing so can lead to returning crises, cascading effects, or catastrophic events to worsen.

With the speed of global changes, it is unlikely that the world can ever return to a precrisis state or opt to reach it. Instead, each crisis could pose an opportunity to act rightly and responsibly, namely, to aid just transitions to sustainability. Former US President Obama’s White House Chief

of Staff Rahm Emanuel once said, “You never want a serious crisis to go to waste,” (114) referring to the possibility of enacting a policy that could not be placed before. With increasing frequency and severity of crises, yet an overwhelmingly worrying lack of appropriate responses, this seems to be more pressing than ever.

SUMMARY POINTS

1. We found a common understanding of the polycrisis in the literature, which we synthesized by defining it as “multiple co-occurring, causally entangled crises with synergistic and cascading effects on multiple systems, degrading humanity’s prospects.”
2. However, the literature reveals high variation in the number, type, and specificity of the listed crises comprising the polycrisis. We identified up to 24 crises comprising it.
3. Most authors agree on an environmental crisis and a socio-political crisis, where climate change and the human health crisis are most frequently mentioned.
4. As drivers of the polycrisis, many publications describe crises driving other crises, whereas others mentioned more systemic drivers.
5. Five drivers of the polycrisis are mentioned frequently but not always accompanied by an analysis of their causal mechanisms: the prevalent economic system, our societal norms and values, the agrifood system, overconsumption, and land use (change).
6. The proposed interventions overwhelmingly focus on deep systemic changes of values and the economy, aligning with the identified key drivers.
7. Our analysis highlights a need to address the polycrisis as a whole and to move beyond siloed responses to individual crises, which will likely require fundamental changes in our societies and our economic system.

FUTURE ISSUES

1. A better understanding is needed of the interconnections among the crises and their drivers, potentially using dynamic systems modeling to explore feedback mechanisms and indirect relations.
2. Future work should include a broader range of scientific, political, and societal perspectives in the literature to broaden views on problems and solutions and engage a wider range of actors in addressing it.
3. It is important to investigate and map which regions and social groups are, and will be, most affected in the future, based on a range of alternative scenarios.
4. Possible interventions should be synthesized from the large existing literature on specific crises, drivers, regions, or contexts and quantify their potential impact. This includes the identification of key actors responsible for implementation, and investigation of synergies and trade-offs among interventions.
5. Efforts should be made to strengthen interventions implementing transformative change by deepening the understanding of key actors and potential barriers, including lock-ins, power relations, and sources of resistance.

6. There is a great need for better harmonization of existing knowledge systems and frameworks across disciplines, including expert panels (e.g., IPCC, IPBES), global bodies (e.g., UN Food and Agriculture Organization, World Health Organization, World Trade Organization), and sustainability frameworks (e.g., UN's Sustainable Development Goals, planetary boundaries, doughnut economy) to foster collective action and effective communication to policymakers, businesses, and the public.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

AUTHOR CONTRIBUTIONS

J.J.R. contributed to conceptualization, formal analysis, investigation, writing the original draft, reviewing, and editing. L.N.S. contributed to conceptualization, formal analysis, investigation, visualization, writing the original draft, reviewing, and editing. R.v.K. contributed to conceptualization, formal analysis, investigation, visualization, writing the original draft, reviewing, and editing. I.H. contributed to conceptualization, investigation, formal analysis, writing the original draft, reviewing, and editing. A.A. contributed to conceptualization, investigation, writing, reviewing, and editing. G.H. contributed to conceptualization, formal analysis, visualization, writing, reviewing, and editing. J.R. contributed to conceptualization, writing, reviewing, and editing. F.C. contributed to conceptualization, reviewing, and editing. G.P. contributed to conceptualization, formal analysis, writing the original draft, reviewing, and editing.

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